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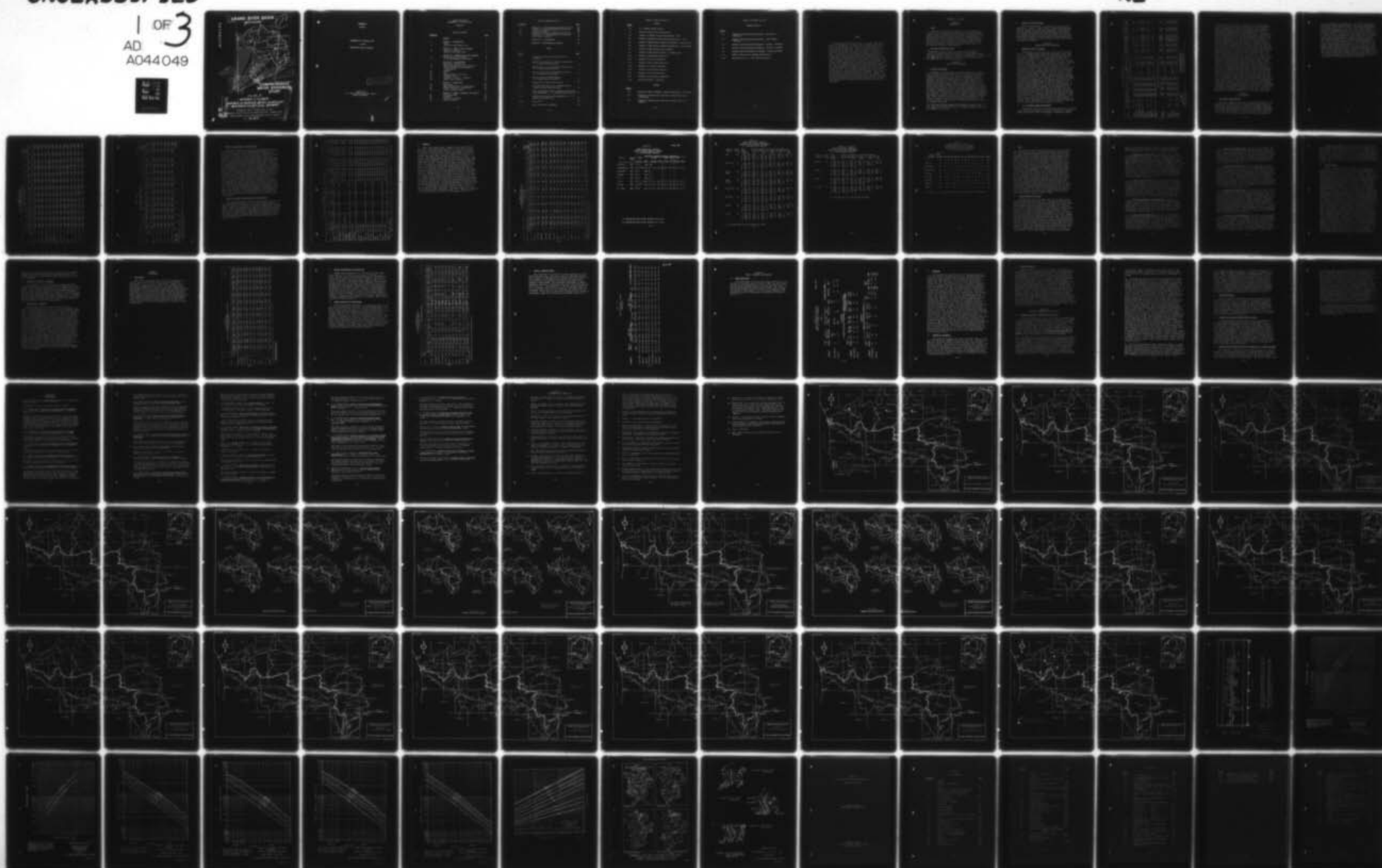

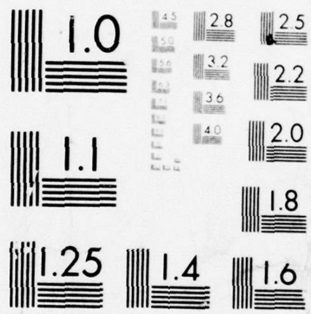
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GRAND RIVER BASIN
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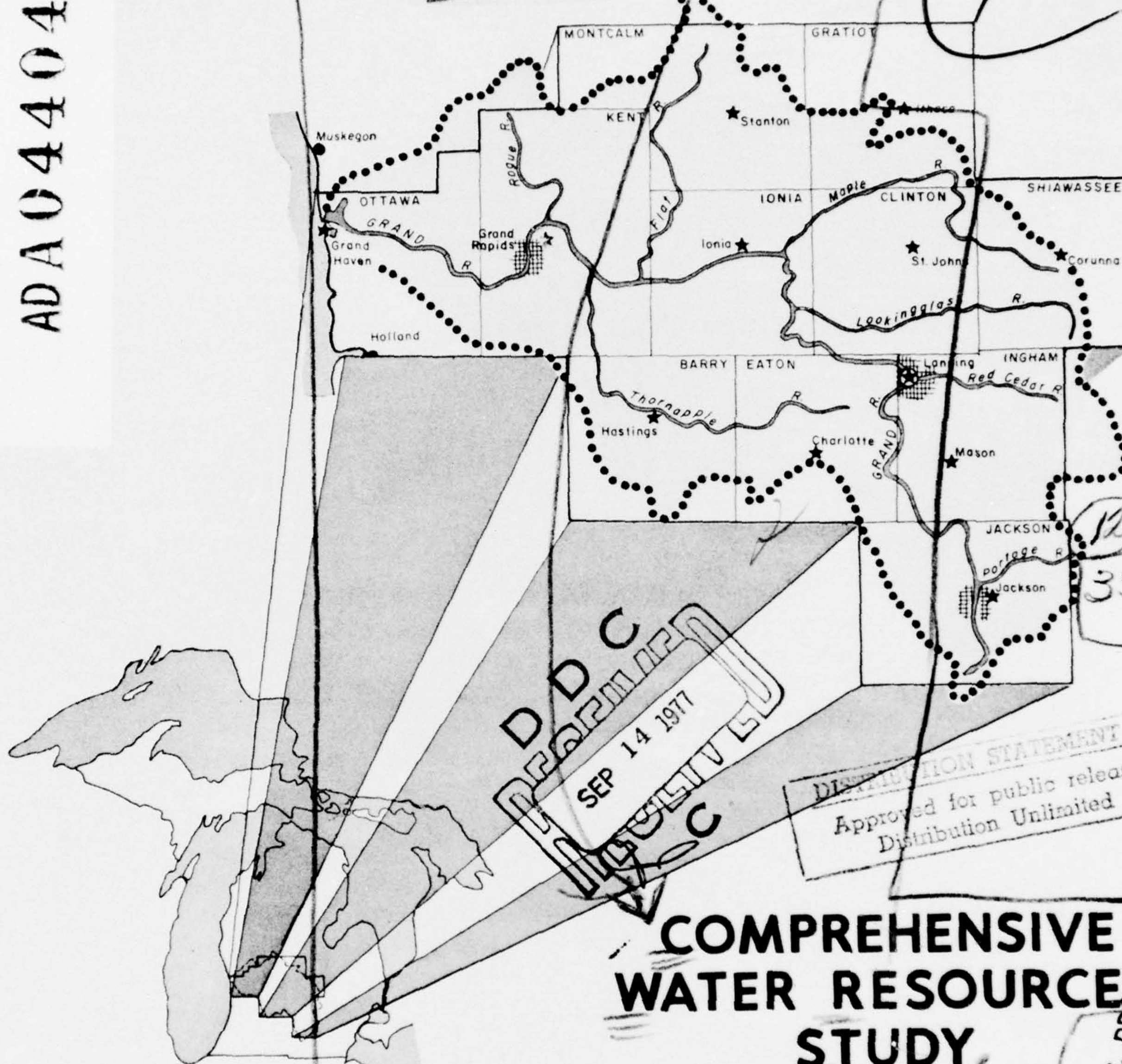

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COMPREHENSIVE WATER RESOURCES STUDY

VOLUME III

APPENDIX C—CLIMATE

APPENDIX D—SURFACE WATER HYDROLOGY & HYDRAULICS & FLUVIAL SEDIMENT

Prepared Under Supervision of the
GRAND RIVER BASIN COORDINATING COMMITTEE
Chairmanship: U. S. Army Engineer District, Detroit

May 1970

APPENDIX C

CLIMATE

COMPREHENSIVE PLANNING STUDY

OF THE

GRAND RIVER BASIN, MICHIGAN

Compiled by
U. S. Army Engineer District, Detroit
Corps of Engineers

GRAND RIVER BASIN
COMPREHENSIVE PLANNING STUDY

APPENDIX C

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SUMMARY

The Grand River basin has two types of climate. The eastern portion of the Basin has a climate that alternates between continental and semi-marine. The marine type is predominant in the western portion of the Basin. The marine type is due to the influence of Lake Michigan, the degree and extent of which are determined by the force, direction, and physical properties of the wind. The Basin has an average annual precipitation of over 31 inches, with a fairly uniform distribution throughout the year. Average annual snowfall amounts range from about 35 inches in the eastern portion of the Basin to over 60 inches in the western portion of the Basin, with the Basin average just over 45 inches. The average annual temperature is 48°, with the maximum monthly average of 72° in July and the minimum monthly average of 23° in January. The average growing season extends from the first week in May to the first week in October. The prevailing winds are from the southwest at about 10 MPH. On the average during each year, the percent possible sunshine is about 50 percent with considerably more cloudy days observed in the western section of the Basin. Average annual relative humidity varies from 60 percent during the afternoon hours to 80 percent during the early morning hours. Detailed information and data concerning these climatological phenomena are described in this appendix and are illustrated in the tables and on the plates and figures.

APPENDIX C - CLIMATE

SECTION I
INTRODUCTION

1. SCOPE

Climate may be defined as a summary of all the weather that a specified area has experienced from day to day over an extended period of years. Climate can also be defined as a measure of average weather conditions that have existed for a specified area. Broadening the scope of climatic conditions to several observation points provides for the development of a general climatic summary for large areas. The climate of the Grand River basin was determined in this manner. Climatological data and their sources for the Basin are presented in this appendix.

2. NEED FOR CLIMATOLOGICAL DATA

GRAND RIVER

Optimum utilization of water resources within the GRAND RIVER Basin requires a thorough knowledge of the Basin's climate with particular regard to its effect on floods, droughts, and availability of water. THIS REPORT Evaluat~~ions~~ES ~~of~~ the potential utilization of water resources for the Basin ~~are~~ made from climatological data.

SECTION II
MAJOR CLIMATE CONTROLS

3. EFFECTS OF LATITUDE

The Basin is located between the 42° 00' and 43° 35' latitudes. These latitudes are the predominant factor in determining climatic conditions within the Basin (1). The most noteworthy latitude influences are on the Basin's precipitation, temperature, and wind movement. The Basin is located between the source regions of contrasting bodies of polar and tropical air. Large bodies of air are technically referred to as air masses. Interactions of these air masses create rapidly changing and complex weather patterns. Frontal storms develop from the interactions of these contrasting air masses. The term front refers to a zone of convergence between two contrasting air masses. Temperatures are affected by the latitude and the angle of incidence of solar radiation. Solar radiation intensity is greatest when the angle is normal to the earth's surface. Surface temperatures experienced in the Basin often develop unstable atmospheric conditions that produce convective-type storms during the summer months. The Basin is located in the latitudes where prevailing winds are often from the southwest. These climatic conditions are discussed in detail in subsequent paragraphs.

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(1) The number inserted between the parenthesis refers to the bibliography at the end of the paper. A particular page is referenced by a diagonal, eg., (1/12).

4. EFFECTS OF THE GREAT LAKES

The Great Lakes operate as a modifier on practically all components of climate. Similar ranges of summer and winter temperatures are generally experienced by areas of the same general latitude; however, the Great Lakes modify these conditions to a cooler summer and milder winter within the Basin. The extent of this modification depends on the force and direction of the wind. The modifying effects of the Great Lakes on various significant climatological components within the Basin are described in detail in subsequent paragraphs.

SECTION III
HYDROCLIMATIC DATA GATHERING

5. NUMBER AND TYPE OF STATIONS

Climatological records have been compiled within the Basin by the U. S. Weather Bureau since 1864 at Lansing. Record dates for all U. S. Weather Bureau stations within the Basin are from the station's beginning up to, and including, December 1964 unless otherwise noted. The U. S. Weather Bureau presently is engaged, or cooperates, in collecting weather data at 20 locations within the Basin (2). In addition, there are 10 weather collecting stations located within 15 miles of the Basin's boundaries (2). Locations of stations within the Basin are shown on plate C-1. Each of the 20 stations located within the Basin records daily precipitation rates (2). Seven of these stations are equipped with continuous recording instruments which provide hourly records (3). Fourteen stations within the Basin record daily snowfall, snowdepth, and monthly snowfall amounts. Records for these fourteen stations are published (2). Daily snowfall amounts and snowdepths are published for four of these stations (2). Recorded daily snowfall amounts and snowdepths for the remaining 10 stations can be obtained from the Weather Bureau at Lansing, Michigan, or the National Weather Records Center at Asheville, North Carolina. In addition, water equivalents of snow cover are measured daily at Lansing and Grand Rapids, Michigan, and published monthly (2). Daily maximum and minimum temperatures are recorded at 10 sites within the Basin (2). Prior to 1948, stations that recorded precipitation and temperature also recorded prevailing wind direction and cloudiness (2). Cloudiness, humidity, and wind data are presently published only for Grand Rapids (4) and Lansing (5). These data are also collected at Jackson and are available from the National Weather Records Center at Asheville, North Carolina, and Jackson. The climatological data collected at stations within and near the Grand River basin are presented in table C-1.

6. U. S. WEATHER BUREAU PUBLICATIONS

Weather data described in the preceding paragraphs for stations within and near the Basin are presented in various U. S. Weather Bureau publications. Daily precipitation, maximum and minimum

TABLE C-1
GRAND RIVER BASIN, MICHIGAN
CLIMATOLOGICAL DATA COLLECTED BY U.S.W.B. STATIONS

STATION	PRECIPITATION						SNOWFALL				TEMPERATURE		WINDS		HUMIDITY AND CLOUDINESS	RECORD DATE
	HOURLY	RECORD DATE	DAILY	RECORD DATE	MONTHLY	RECORD DATE	DAILY	RECORD DATE	MONTHLY	RECORD DATE	DAILY & MONTHLY	RECORD DATE	SPEED & DIR.	RECORD DATE		
						STATIONS LOCATED WITHIN GRAND RIVER BASIN										
Casnovia	X-HPD	1942	X-MCD	1942	X-MCD	1942										
Charlotte			X-MCD	1903	X-MCD	1903			X-MCD	1903	X-MCD	1903	T-1948	1897	T-1948	1897
East Lansing	X-HPD	1957	X-MCD	1957	X-MCD	1957					X-MCD	1957				
Eaton Rapids			X-MCD	1941	X-MCD	1941			X-MCD	1941						
Grand Haven FD	T-1932	1902	X-MCD	1894	X-MCD	1894	T-1932	1892	X-MCD	1892	X-MCD	1873	T-1932	1897	T-1932	1897
Grand Haven SP	X-HPD	1942	X-MCD	1942	X-MCD	1942										
Grand Ledge			X-MCD	1941	X-MCD	1941			X-MCD	1941						
Grand Rapids AP	X-HPD	1903	X-MCD	1894	X-MCD	1870	X-MCD	1894	X-MCD	1894	X-MCD	1887	X-LCD	1903	X-LCD	1903
Greenville			X-MCD	1913	X-MCD	1913			X-MCD	1913	X-MCD	1913	T-1948	1913	T-1948	1913
Hastings			X-MCD	1896	X-MCD	1896			X-MCD	1896	X-MCD	1896	T-1948	1897	T-1948	1897
Ionia			X-MCD	1939	X-MCD	1939			X-MCD	1939	X-MCD	1939	T-1948	1939	T-1948	1939
Jackson 3N	X-HPD	1940	X-MCD	1940	X-MCD	1940										
Jackson AP			X-MCD	1897	X-MCD	1897	X-MCD	1897	X-MCD	1897	X-MCD	1897	T-1948	1897	T-1948	1897
Kent City			X-MCD	1941	X-MCD	1941			X-MCD	1941						
Lansing AP(1)	X-HPD	1910	X-MCD	1864	X-MCD	1864	X-MCD	1911	X-MCD	1887	X-MCD	1864	X-LCD	1887	X-LCD	1910
Lowell (2)			X-MCD	1915	X-MCD	1915			X-MCD	1915						
McBride			X-MCD	1938	X-MCD	1938			X-MCD	1938						
St. Johns(3)			X-MCD	1887	X-MCD	1887	X-MCD	1949	X-MCD	1887	X-MCD	1887	T-1948	1897	T-1948	1897
Stanton	X-HPD	1957	X-MCD*	1957	X-MCD*	1957										
Williamston			X-MCD	1931	X-MCD	1931										
						TERMINATED STATIONS LOCATED WITHIN GRAND RIVER BASIN										
Saranac			T-1939	1879	T-1939	1879			T-1939	1879	T-1939	1879	T-1939	1897	T-1939	1897
Weber Dam			T-1939	1913	T-1939	1913			T-1939	1913	T-1939	1913	T-1913	1913	T-1939	1913
Weberville			T-1910	1901	T-1910	1901			T-1910	1901	T-1910	1901	T-1910	1901	T-1910	1901
						STATIONS BORDERING GRAND RIVER BASIN										
Albion			X-MCD	1888	X-MCD	1888			X-MCD	1888	X-MCD	1888	T-1948	1897	T-1948	1897
Allegan	X-HPD	1940	X-MCD	1888	X-MCD	1888			X-MCD	1888	X-MCD	1888	T-1948	1897	T-1948	1897
Alma			X-MCD	1887	X-MCD	1887			X-MCD	1887	X-MCD	1887	T-1948	1897	T-1948	1897
Ann Arbor	X-HPD	1951	X-MC	1880	X-MCD	1880			X-MCD	1880	X-MCD	1880	T-1948	1897	T-1948	1897
Battle Creek			X-MCD	1876	X-MCD	1876	X-MCD	1949	X-MCD	1876	X-MCD	1876	T-1948	1897	T-1948	1897
Big Rapids			X-MCD	1893	X-MCD	1893	X-MCD	1949	X-MCD	1873	X-MCD	1873	T-1948	1897	T-1948	1897
Holland			X-MCD	1905	X-MCD	1905			X-MCD	1905	X-MCD	1905	T-1948	1905	T-1948	1905
Howell	X-HPD	1961	X-MCD	1890	X-MCD	1890			X-MCD	1890	T-1928	1890	T-1928	1897	T-1948	1897
Muskegon	X-HPD	1941	X-MCD	1896	X-MCD	1896	X-MCD	1941	X-MCD	1896	X-MCD	1896	X-LCD	1897	X-LCD	1897
Owosso			X-MCD	1896	X-MCD	1896			X-MCD	1896	X-MCD	1896	T-1948	1897	T-1948	1897

SYMBOLS
X - Presently operated
T - Terminated
(1)Also known as East Lansing W.B. City
(2)Also known as Edmore
(3)Station closed 1909 to 1938

U.S. Weather Bureau Publications
MCD - Monthly Climatological Data
HPD - Hourly Precipitation Data
LCD - Local Climatological Data
*Monthly Summary of Only Hourly Recording Stations

temperatures, snowfall amounts, snowdepths, and water equivalents of snow cover are presently published in monthly "Climatological Data" for Michigan (2). Monthly precipitation, mean, maximum, minimum, and normal temperatures, and freeze data are presented in the annual "Climatological Data" for Michigan (6). A "Local Climatological Summary" with comparative data is also published for both the Grand Rapids (4) and Lansing (5) stations. Data include normals, means, and extremes for precipitation, temperatures, wind velocity and direction, and cloudiness and humidity. Means and extremes of precipitation and temperatures are also published in "Climate of Michigan by Stations" (7) and in "Climatic Summary of the United States - Michigan" (8), which are supplements covering the period from the establishment of stations to the year 1930 and the years 1931 to 1952; and 1953 to 1960, inclusive. Hourly precipitation data have been published in "Hourly Precipitation Data" for Michigan from 1951 to the present (3). From 1948 to 1951, hourly rates were published in monthly "Climatological Data" (2). From 1940 to 1948, hourly rainfall rates were recorded in "Daily and Hourly Precipitation for Region 3 - Ohio River" (9). Prior to 1940, hourly precipitation rates were recorded at only Grand Rapids and Lansing and at Grand Haven to 1932. Published records for these years are available from the individual stations. Daily snowfall amounts for Lansing and Grand Rapids were first published in the monthly publication "Climatological Data - November 1943" (2). Daily snowfall and snowdepths for Grand Rapids, Jackson, Lansing, and St. Johns have been published since 1949 in monthly "Climatological Data" (2). In addition, water equivalents of snow depth for Grand Rapids and Lansing have been published from 1952 to the present in monthly "Climatological Data" (2). Annual season snowfall amounts have been published in June editions of "Climatological Data" (2) since 1950. Annual snowfall amounts were not published from 1948 to 1950. In addition, average annual snow depths for stations within the Basin for the period 1931 to 1960 are reported in "Michigan Snow Depths" (10). The U. S. Weather Bureau has also published monthly "Storm Data" for Michigan from 1959 to the present (11). Information contained in this publication describes in general the types of storms and damages resulting from the storms. Prior to 1959, storm data were presented in monthly "Climatological Data" (2). The detail in description of storms was dependent on the severity of the storm.

SECTION IV
PRECIPITATION

7. MEAN ANNUAL PRECIPITATION

The Basin averages 31.43 inches of precipitation annually. For stations with at least 50 years of record, the maximum mean annual precipitation is 33.46 inches, recorded at Grand Rapids, while the minimum mean annual rainfall is 29.73 inches, recorded at Charlotte. An isohyetal map showing the distribution of mean annual precipitation is presented on plate C-2. The greater mean annual precipitation amounts for the western portion of the Basin is explained by

its close proximity to Lake Michigan. Air masses in the section of the state carry considerably more moisture from Lake Michigan than do the interior land air masses. The maximum annual precipitation that has occurred in the entire Basin is 52.14 inches recorded at Grand Rapids in 1883. The minimum annual rainfall that has been experienced in the whole Basin is 18.50 inches recorded at Lansing in 1930. Average annual precipitation data from 1920 to 1963 for the entire Basin are shown in figure C-1. The greatest average annual precipitation for the whole Basin since 1920 is 38.05 inches, computed in 1942 in which the maximum rainfall of 42.71 was recorded at Hastings, and the minimum precipitation of 31.81 inches was recorded at Greenville. An isohyetal map of the maximum average annual precipitation is shown on plate C-3. The minimum average annual rainfall for the entire Basin since 1920 of 20.55 inches was computed in 1930. The maximum precipitation for 1930 of 22.77 inches was recorded at Lowell, and the minimum rainfall of 18.50 inches was recorded at Lansing. An isohyetal map of the minimum average annual precipitation for 1930 is shown on plate C-4. Extreme and mean annual precipitation amounts for stations located within the Basin are presented in table C-2.

March 1967

TABLE C-2
GRAND RIVER BASIN, MICHIGAN
MEAN AND EXTREME ANNUAL - MONTHLY PRECIPITATION
U. S. WEATHER BUREAU STATIONS

(1)
MEAN AND EXTREME MONTHLY PRECIPITATION

Station	Record Dates	Jan. Mean	Jan. Max./Min.	Feb. Mean	Feb. Max./Min.	Mar. Mean	Mar. Max./Min.	Apr. Mean	Apr. Max./Min.	May Mean	May Max./Min.	June Mean	June Max./Min.
		In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
Casnovia	1949	1.49	2.84/0.29	1.59	2.72/0.27	1.95	3.11/0.47	3.14	5.42/1.83	3.16	6.33/0.97	2.61	4.30/0.75
Charlotte	1903	1.74	3.98/0.14	1.47	4.12/0.23	2.01	4.43/0.06	2.76	7.24/0.62	3.54	7.53/0.64	3.57	8.69/0.63
Eaton Rapids	1941	1.85	3.84/0.17	1.66	4.76/0.37	2.35	4.36/0.33	3.14	7.14/0.69	3.51	9.23/0.7[illegible]	3.68	8.11/1.10
East Lansing Hort. Farm	1957	1.44	2.82/0.14	1.07	1.78/0.74	1.35	2.12/0.47	2.43	3.45/1.59	2.57	5.63/1.04	2.71	3.89/1.68
Grand Haven Fire Dept.	1891	2.36	4.40/0.38	1.94	4.48/0.09	2.28	5.85/0.24	2.69	8.43/0.65	3.25	6.73/0.92	3.13	9.35/0.37
Grand Haven Sewage Plt.	1949	1.84	3.96/0.26	1.66	2.65/0.44	2.01	3.03/0.59	2.86	4.76/1.20	2.57	6.25/1.03	2.71	6.49/0.27
Grand Ledge	1941	1.69	3.97/0.12	1.54	3.44/0.37	2.08	3.40/0.54	2.81	5.85/0.73	3.33	7.23/0.40	3.68	6.43/1.62
Grand Rapids AP	1870	2.37	6.00/0.29	2.04	7.87/0.02	2.49	6.88/0.08	2.84	8.29/0.39	3.29	7.18/0.72	3.47	13.22/0.39
Greenville	1912	1.67	5.25/0.19	1.59	5.48/0.11	2.12	6.32/0.26	2.68	6.38/0.58	3.28	6.75/0.58	3.27	7.21/1.18
Hastings	1879	1.88	6.40/0.28	1.77	4.66/0.19	2.29	5.05/0.24	2.70	7.80/0.57	3.65	7.49/0.66	3.63	7.68/0.83
Ionia	1939	1.47	3.18/0.27	1.40	2.41/0.19	1.94	4.65/0.63	3.22	6.03/0.83	3.65	7.68/0.65	3.44	5.97/1.39
Jackson 3N	1949	1.84	4.00/0.73	1.86	4.13/0.40	2.13	3.74/0.48	3.25	5.75/1.75	2.65	7.30/0.25	3.03	5.50/0.64
Jackson AP	1897	1.82	4.39/0.32	1.78	6.34/0.38	2.24	4.50/0.13	2.87	7.13/0.69	3.56	11.52/0.78	3.63	11.69/0.34
Kent City	1931	1.91	4.19/0.41	1.83	5.65/0.06	2.13	5.26/0.49	2.84	6.77/0.60	3.41	6.82/0.60	3.14	4.93/0.39

Station	July Mean	July Max./Min.	Aug. Mean	Aug. Max./Min.	Sept. Mean	Sept. Max./Min.	Oct. Mean	Oct. Max./Min.	Nov. Mean	Nov. Max./Min.	Dec. Mean	Dec. Max./Min.	Annual Precip. Mean	Annual Precip. Max./Min.
	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
Casnovia	3.04	7.32/0.45	3.37	8.82/1.10	2.69	8.17/1.00	2.68	7.36/0.40	2.59	4.07/0.55	1.45	2.76/0.43	29.76	40.62/19.81
Charlotte	2.52	6.49/0.00	2.74	9.80/0.66	3.05	9.15/0.28	2.51	7.80/0.10	2.13	5.66/0.56	1.69	4.31/0.35	29.73	41.88/21.33
Eaton Rapids	2.91	6.31/0.63	2.58	6.32/0.31	2.61	6.16/0.43	2.55	7.80/0.14	2.05	3.67/0.44	1.61	4.32/0.19	30.50	39.26/21.74
East Lansing Hort. Farm	3.96	8.17/1.78	1.99	4.25/1.36	2.25	3.98/1.16	2.78	4.97/0.44	1.59	2.58/0.40	0.98	2.09/0.10	25.62	35.84/20.39
Grand Haven Fire Dept.	[illegible].55	7.96/0.19	2.78	8.83/0.42	3.45	9.37/0.67	2.88	8.56/0.20	2.80	8.02/0.00	3.06	6.80/0.51	33.17	47.89/21.15
Grand Haven Sewage Plt.	3.11	6.65/0.52	2.25	3.78/0.90	2.37	7.47/0.61	2.61	7.75/0.41	2.48	3.69/1.20	2.18	5.36/0.46	28.65	40.67/21.85
Grand Ledge	2.98	6.41/0.16	2.45	5.09/0.60	2.97	6.79/0.37	2.10	6.30/0.30	1.94	3.85/0.57	1.60	3.26/0.25	29.17	40.11/21.01
Grand Rapids AP	3.49	9.35/0.25	2.53	7.40/0.11	3.36	10.03/0.27	2.84	8.76/0.23	2.60	6.82/0.06	2.14	6.95/0.31	33.46	52.14/20.92
Greenville	3.25	7.97/0.23	3.12	6.38/0.29	3.26	8.47/0.94	2.60	7.44/0.35	2.42	5.18/0.49	1.85	5.03/0.26	31.11	42.23/20.30
Hastings	2.89	7.33/0.40	2.97	9.17/0.10	3.25	8.56/0.39	2.78	10.51/0.19	2.46	5.64/0.20	2.07	5.64/0.20	32.34	45.94/19.11
Ionia	2.88	8.02/0.31	3.33	6.91/0.95	2.70	6.06/0.42	2.54	6.48/0.28	2.20	4.18/0.53	1.74	4.66/0.37	30.51	38.82/21.49
Jackson 3N	3.01	5.02/1.32	2.77	5.00/0.97	2.05	3.94/0.30	2.65	7.66/0.23	2.01	3.79/0.56	1.49	3.62/0.36	28.74	40.08/19.96
Jackson AP	3.66	7.11/0.22	2.62	7.43/0.56	2.88	7.82/0.38	2.53	6.59/0.21	2.25	5.50/0.07	1.82	3.94/0.28	31.66	41.96/19.88
Kent City	3.11	7.34/0.26	3.21	7.58/0.26	3.36	8.37/1.01	2.63	6.62/0.47	2.83	6.64/0.52	1.97	4.63/0.28	32.36	40.50/22.44

TABLE C-2 (Cont'd)

Station	Record Dates	Jan. Mean	Jan. Max./Min.	Feb. Mean	Feb. Max./Min.	Mar. Mean	Mar. Max./Min.	Apr. Mean	Apr. Max./Min.	May Mean	May Max./Min.	June Mean	June Max./Min.	July Mean	July Max./Min.	Aug. Mean	Aug. Max./Min.	Sept. Mean	Sept. Max./Min.	Oct. Mean	Oct. Max./Min.	Nov. Mean	Nov. Max./Min.	Dec. Mean	Dec. Max./Min.	Mean and Extreme Annual Precip. Mean	Mean and Extreme Annual Precip. Max./Min.
		In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
Lansing AP	1864	1.82	4.17/0.36	1.81	7.47/0.00	2.37	5.60/0.43	2.55	6.40/0.61	3.18	7.98/0.70	3.54	11.35/0.97	3.00	11.27/0.09	2.74	9.21/0.00	2.77	7.76/0.53	2.41	7.33/0.04	2.21	5.10/0.04	1.85	4.70/0.37	30.25	48.44/18.50
Lowell	1915	1.86	3.83/0.30	1.64	5.48/0.32	2.46	7.12/0.71	2.82	6.42/0.22	3.51	7.69/0.97	3.22	6.91/0.43	3.27	6.54/0.46	2.77	7.33/0.37	3.52	8.05/0.86	2.64	7.93/0.15	2.49	5.10/0.54	2.07	4.56/0.30	32.27	42.78/22.70
McBride	1938	2.08	4.68/0.40	1.33	2.91/0.36	2.22	4.47/0.62	2.41	5.83/0.67	3.06	5.65/1.08	3.32	6.04/0.87	3.42	8.64/0.81	3.57	7.21/0.42	3.31	6.86/0.96	2.04	5.78/0.25	2.46	4.14/0.57	1.82	4.15/0.30	31.04	39.90/23.66
St. Johns	1887	1.77	4.69/0.25	1.52	3.80/0.14	2.14	4.72/0.19	2.61	5.35/0.51	3.31	6.92/1.08	3.35	7.28/1.13	2.91	7.14/0.68	3.11	7.56/0.03	2.88	8.00/0.76	2.40	6.82/0.17	2.21	3.69/0.53	1.82	4.71/0.23	30.63	41.50/20.03
Stanton	1957	1.62	2.88/0.34	1.52	2.45/0.24	1.78	3.41/0.86	2.94	3.74/1.43	2.21	3.88/1.41	3.39	4.33/1.26	2.71	4.72/1.21	3.02	4.54/1.00	2.63	6.15/1.00	2.29	4.25/0.39	2.59	3.49/0.73	1.41	2.92/0.43	28.11	36.31/21.59
Williamston	1931	1.68	5.46/0.20	1.79	5.67/0.27	2.28	4.98/0.39	2.79	5.88/0.50	3.69	7.85/0.85	3.90	7.53/1.53	3.12	9.24/0.17	3.01	5.99/0.70	2.41	5.16/0.57	2.46	7.65/0.15	1.99	3.71/0.50	1.62	3.40/0.33	30.74	46.17/19.97
Grand River Basin Mean Precip. (2)		1.87		1.73		2.27		2.88		3.36		3.37		3.11		2.81		3.11		2.62		2.38		1.92		31.43	38.05/20.55

(1) Means computed from record date to 1964

(2) *Grand River basin mean precipitation* values determined from averaging all U.S. Weather Bureau stations with at least 50 years of record located in and near the Grand River basin

8. MONTHLY DISTRIBUTION OF PRECIPITATION

Rainfall distribution is fairly uniform throughout the year within the Basin. The average maximum monthly rainfall is 3.37 inches in June, and the average minimum monthly precipitation is 1.73 inches in February. About sixty percent of the annual precipitation occurs in the spring and summer months of April thru September. The greatest variation from the mean monthly precipitation of 3.11 inches for this six-month period is only 0.30 inches, and the greatest variation from the mean monthly precipitation of 2.11 inches for the fall-winter months is 0.38 inches. The greatest monthly rainfall within the Basin of 13.22 inches was recorded at Grand Rapids in June 1883, while the minimum monthly precipitation of 0.00 inches has been recorded at Charlotte, Grand Haven and Lansing at various times. Extreme and mean monthly precipitation for stations located within the Basin are presented in table C-2. Isohyetal maps of the monthly distribution of precipitation are shown on plates C-5 and C-6. The western portion of the Basin receives more precipitation during the winter months than the eastern portion of the Basin, while the converse is true during the summer months. This is explained by the modifying effects of Lake Michigan. During the winter months, air masses moving over the relatively warm Lake Michigan waters pick up additional moisture and at the same time become more unstable by heating from the lake. As a result, the amount and frequency of precipitation are greater for this area. In the summer months, the stabilizing effect of the relatively cool Lake Michigan waters on passing air masses reduces the amount of precipitation for the western portion of the Basin.

9. DIURNAL AND HOURLY DISTRIBUTION OF PRECIPITATION

Daily rainfall amounts in excess of 3 inches have been recorded at each station within the Basin. The maximum 24-hour rainfall within the Basin of 5.89 inches was recorded at Webberville, located about 16 miles east of Lansing, 5-6 June 1905. The maximum one-hour rainfall within the Basin of 3.20 inches was recorded at Grand Haven, 20 June 1954. Significantly, this rainfall is reported to have occurred in a 20-minute period. Such high rainfall intensity rates are usually a result of thunderstorm activity. Maximum hourly and daily precipitation rates for stations within the Basin are presented in table C-3.

TABLE C-3
GRAND RIVER BASIN, MICHIGAN
MAXIMUM HOURLY AND DAILY RECORDED PRECIPITATION - U.S. WEATHER BUREAU STATIONS

Station	Type of Gage	Record Date	PRECIPITATION RATES															
			1-Hr. In.	Date	3-Hr. In.	Date	6-Hr. In.	Date	12-Hr. In.	Date	24-Hr. In.	Date	48-Hr. In.	Date	72-Hr. In.	Date	96-Hr. In.	Date
Casnovia	R	1947	2.09	13 Jun 61	2.94	20 Aug 58	4.39	20 Aug 58	4.39	20 Aug 58	4.46	20 Aug 58	4.73	Oct 54	4.85	Oct 54	4.89	Oct 54
Charlotte	NR	1926									3.53	6 Jul 34	3.94	Aug 58	6.26	Sep 50	6.49	Sep 50
East Lansing Hort. Farm	R-NR	1957	1.04	31 May 58	2.42	6 Jun 63	2.54	6 Jun 63	2.54	6 Jun 63	3.22	11 Jul 57	3.63	Jul 57	3.63	Jul 57	5.07	Jul 57
Eaton Rapids	NR	1941									3.18	13 Sep 50	4.02	Oct 54	4.21	Oct 54	4.64	Sep 50
Grand Haven Fire Dept.	NR	1960	3.20 (1)	20 Jun 54							4.19	2 Aug 15	5.99	Aug 15	6.18	Aug 15	6.26	Aug 15
Grand Haven Sewage Plant	R	1940	1.92	20 Jun 54	2.74	20 Jun 54	3.24	20 Jun 54	3.36	3 Oct 54	4.41	3 Oct 54	4.60	Oct 54	4.70	Oct 54	4.70	Oct 54
Grand Ledge	NR	1926									4.52	7 Sep 42	5.16	Sep 42	5.22	Sep 42	5.22	Sep 42
Grand Rapids AP	R-NR	1904	2.21	26 Jun 09	2.78	26 Jun 09	3.26	11 Aug 39	4.17	19 Aug 39	4.58	5 Jun 05	5.12	Jun 05	5.48	Jun 05	5.48	Jun 05
Greenville	NR	1926									3.99	28 Aug 32	4.30	Oct 54	5.66	Sep 31	6.07	Sep 31
Hastings	NR	1926									5.69	19 Aug 39	5.87	Aug 39	5.89	Aug 39	5.89	Aug 39
Ionia	NR	1926									4.10	21 Aug 58	5.06	Aug 58	5.06	Aug 58	5.06	Aug 58
Jackson 3N	R	1940	1.54	11 May 56	2.64	5 Apr 47	3.58	5 Apr 47	4.47	5 Apr 47	4.59	5 Apr 47	4.87	Apr 47	4.87	Apr 47	4.87	Apr 47
Jackson AP	NR	1926									5.31	21 Jun 37	6.36	Jun 37	6.63	Jun 37	6.36	Jun 37
Kent City	NR	1926									3.63	19 Aug 39	3.92	Jul 35	4.32	Jul 35	4.35	Nov 34
Lansing AP	R-NR	1902	2.06	7 Jul 23	3.21	6 Jun 63	4.31	6 Jun 63	4.35	6 Jun 63	5.47	6 Jun 05	5.92	Jun 05	6.03	Jun 05	6.03	Jun 05
Lowell	NR	1926									5.60	30 Aug 55	5.60	Aug 55	5.96	Aug 55	5.97	Aug 55
McBride	NR	1926									5.00	3 Aug 28	5.00	Aug 28	5.00	Aug 28	5.00	Aug 28
St. Johns	NR	1938									3.78	16 Aug 52	3.95	Sep 50	4.03	Sep 50	6.70	Sep 50
Stanton	R	1957	1.25	8 Jul 57	1.82	8 Jul 57	2.10	17 Nov 63	2.10	17 Nov 63	2.23	25 Sep 61	2.70	Sep 63	2.70	Sep 63	2.95	Jul 57
Williamstom	NR	1941									3.23	10 Jun 52	4.24	Oct 54	4.54	Oct 54	4.74	Oct 54
Grand River Basin			3.20	20 Jun 54	3.21	6 Jun 63	4.39	20 Aug 58	4.47	5 Apr 47	5.89 (2)	6 Jun 05	6.36	Jun 37	6.36	Jun 37	6.49	Sep 50

(1) Occurred in 20 minutes
(2) Greatest 24-hour rainfall in Grand River Basin = 5.89 inches - Weberville, 5-6 Jun 1905

R - Recording Gage   NR - Non-Recording Gage

10. SNOWFALL

The average annual snowfall computed for the entire Basin is 45.2 inches. The maximum average snowfall is 60.3 inches at Grand Haven and the minimum average snowfall is 35.1 inches at Charlotte. An isohyetal map of mean annual snowfall distribution is presented on plate C-7. About 85 percent of the annual snowfall occurs from December thru March, with a maximum average of 11.7 inches in January. The maximum seasonal snowfall in the Basin of 132.0 inches was recorded at Grand Rapids during the 1951-1952 winter season. The minimum seasonal snowfall occurred at Jackson in 1952-1953 when 14.6 inches were recorded. Extreme and mean annual and monthly snowfall amounts for stations located within the Basin are presented in table C-4. An isohyetal map showing the average monthly distribution of snowfall is presented as plate C-8. The maximum 24-hour snowfall rate of 18.1 inches was recorded at Lansing, in November 1921. Maximum daily snowfall amounts recorded within the Basin are presented in table C-5. Maximum recorded snow depths for the period of 1931 thru 1964 range from 20 inches in the extreme eastern portion of the Basin to 50 inches in the extreme western section of the Basin (10). The U. S. Weather Bureau (12) has developed the frequency of maximum water equivalents of snowfall for Grand Rapids and Lansing during the first and last two weeks of March. These relationships are shown on figures C-2 and C-3, respectively. The Michigan Department of Agriculture has developed and published in "Michigan Snowfall Statistics; First 1-, 3-, 6-, 12-Inch Depths" (30), maps of the Mean Dates of First 3-, 6-, and 12-Inch snow depths in Michigan. The parts of these maps applicable to the Basin are reproduced in Figure C-10. Tables of probability of first snow occurrence (30) have been reproduced in table C-6.

TABLE C-4
GRAND RIVER BASIN, MICHIGAN
MEAN AND EXTREME ANNUAL AND MONTHLY SNOWFALL
U.S. WEATHER BUREAU STATIONS

SNOWFALL AMOUNTS

Station	Years of Record	Jan. Mean	Jan. Max./Min.	Feb. Mean	Feb. Max./Min.	Mar. Mean	Mar. Max./Min.	Apr Mean	Apr Max./Min.	May Mean	May Max./Min.	June (2) Mean	June (2) Max./Min.	July (2) Mean	July (2) Max./Min.	Aug. (2) Mean	Aug. (2) Max./Min.	Sept. Mean	Sept. Max./Min.	Oct. Mean	Oct. Max./Min.	Nov. Mean	Nov. Max./Min.	Dec. Mean	Dec. Max./Min.	Mean and Extreme Annual Precip. Mean	Mean and Extreme Annual Precip. Max./Min.
		In.	In.	In	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
Charlotte	52	9.4	23.5/T	7.4	19.7/1.2	6.1	16.0/0.0	1.5	8.2/0.0	0.2	1.5/0.0	0.0	0.0/0.0	0.0	0.0/0.0	0.0	0.0/0.0	0.0	T/0.0	0.2	3.0/0.0	2.8	10.8/0.0	7.5	27.7/0.5	35.1	69.4/16.0
Eaton Rapids	16	9.4	15.5/2.9	8.4	18.0/0.8	7.0	22.0/1.8	1.4	8.8/0.0	0.0	T/0.0	0.0	0.0/0.0	0.0	0.0/0.0	0.0	0.0/0.0	0.0	0.0/0.0	T	T/0.0	3.7	9.3/0.0	6.8	22.7/1.6	36.7	55.8/22.8
Grand Haven FD	72	17.5	57.5/2.0	12.2	32.5/1.4	7.8	32.1/0.0	1.4	10.0/0.0	0.2	1.0/0.0	0.0	T/0.0	0.0	0.0/0.0	0.0	T/0.0	T	T/0.0	0.4	2.1/0.0	6.6	22.5/0.0	14.2	58.5/3.3	60.3	110.0/27.0
Grand Ledge	19	9.1	22.2/1.5	8.9	19.3/1.0	5.8	12.0/1.0	1.4	5.0/0.0	T	T/0.0	0.0	T/0.0	0.0	0.0/0.0	0.0	T/0.0	T	T/0.0	0.1	0.4/0.0	4.0	12.1/T	7.5	17.0/1.5	36.8	52.4/32.4
Grand Rapids AP	70	16.1	42.6/0.8	10.7	27.3/2.4	8.7	25.3/T	2.5	11.2/0.0	0.2	5.5/0.0	0.0	0.0/0.0	0.0	0.0/0.0	0.0	0.0/0.0	T	T/0.0	0.4	7.5/0.0	5.8	26.9/T	13.7	51.3/1.5	58.1	132.0/20.0
Greenville	42	11.5	27.5/T	8.9	31.0/2.0	7.6	18.0/0.0	1.5	7.0/0.0	0.6	2.0/0.0	0.0	0.0/0.0	0.0	0.0/0.0	0.0	0.0/0.0	0.0	T/0.0	0.2	2.0/0.0	3.7	16.0/0.0	9.4	31.0/T	43.4	91.9/23.3
Hastings	62	9.8	24.8/T	9.1	24.0/1.5	7.7	19.0/0.0	1.8	8.0/0.0	0.2	0.2/0.0	0.0	0.0/0.0	0.0	0.0/0.0	0.0	0.0/0.0	T	T/0.0	0.2	2.0/0.0	4.0	12.0/0.0	9.0	28.0/2.3	41.8	56.6/20.9
Ionia	14	9.4	15.5/3.0	9.0	14.7/1.0	7.2	17.0/T	0.8	6.0/0.0	T	T/0.0	0.0	T/0.0	0.0	0.0/0.0	0.0	0.5/0.0	0.0	0.0/0.0	T	2.0/0.0	3.2	15.9/0.0	7.3	17.1/1.0	36.9	67.9/19.5
Jackson AP	65	8.9	26.3/3.1	8.9	18.2/1.5	6.3	17.5/0.3	1.2	8.5/0.0	0.1	0.5/0.0	0.0	0.0/0.0	0.0	0.0/0.0	0.0	0.0/0.0	0.0	0.0/0.0	0.2	2.0/0.0	3.2	9.5/T	8.1	21.2/1.1	36.9	68.0/14.6
Kent City	29	11.6	26.5/3.1	10.0	23.0/1.0	8.2	16.1/0.0	1.8	8.0/0.0	0.0	T/0.0	0.0	T/0.0	0.0	0.0/0.0	0.0	0.0/0.0	0.0	0.0/0.0	0.2	4.0/0.0	5.5	16.5/T	9.9	22.7/3.0	47.2	72.7/35.1
Lansing AP	55	11.2	33.6/0.5	10.5	25.4/4.6	8.4	22.2/T	2.4	11.5/0.0	0.4	11.5/0.0	0.0	0.0/0.0	0.0	0.0/0.0	0.0	0.0/0.0	T	0.1/0.0	0.5	5.3/0.0	3.8	21.8/T	9.8	29.3/1.9	47.0	88.8/20.7
Lowell	29	13.0	29.6/3.5	10.6	22.1/3.0	9.6	20.6/3.9	1.8	10.0/0.0	T	4.0/0.0	0.0	T/0.0	0.0	T/0.0	0.0	T/0.0	0.0	0.0/0.0	0.1	2.3/0.0	5.4	20.4/T	10.5	43.0/2.5	51.0	114.2/33.5
McBride	20	13.0	23.5/2.5	10.4	28.9/1.5	9.3	17.5/2.5	1.9	10.0/0.0	0.0	T/0.0	0.0	0.0/0.0	0.0	0.0/0.0	0.0	0.0/0.0	0.0	T/0.0	0.2	5.0/0.0	6.4	13.0/0.0	9.6	28.0/3.5	50.8	99.8/29.0
St. Johns	38	8.7	20.7/2.4	9.0	19.1/2.5	7.4	10.7/0.0	1.9	7.8/0.0	0.0	T/0.0	0.0	0.0/0.0	0.0	T/0.0	0.0	0.0/0.0	0.0	0.0/0.0	0.1	1.0/0.0	4.2	15.7/0.0	7.0	21.0/T	38.3	76.8/19.0
Williamston	15	7.7	14.9/2.4	8.0	14.0/0.3	5.2	9.8/0.5	1.5	7.4/0.0	0.0	T/0.0	0.0	T/0.0	0.0	0.0/0.0	0.0	0.0/0.0	0.0	0.0/0.0	0.1	0.4/0.0	2.2	8.0/0.0	6.0	10.0/2.5	30.7	44.7/20.7
Grand River Basin (1)		11.7		9.7		7.6		1.8		0.3		0.0		0.0		0.0		0.0		0.3		4.1		9.7		45.2	

(1) Mean values determined from U.S. Weather Bureau stations with at least 30 years of record in and near the Grand River basin

(2) Snowfall amounts may be in the form of hail during this month.

Max/Min. Values Recorded from 1926 through 1963

T < 0.1 inches

Table C-5. March 1967

GRAND RIVER BASIN, MICHIGAN
MAXIMUM RECORDED SNOWFALL AMOUNTS
U.S. WEATHER BUREAU STATIONS

Station	Record Date	Durations, Snowfall Amounts, and Dates							
		1-Day		2-Day		3-Day		4-Day	
		Inches	Date	Inches	Date	Inches	Date	Inches	Date
Charlotte	1932	9.0	Feb. 48	-	-	-	-	-	-
Grand Rapids	1943	12.0 (1)	16 Apr 61	15.5	Jan 63	22.4	Dec 51	22.4	Dec 51
Greenville	1932	11.0	Mar 40	-	-	-	-	-	-
Hastings	1930	9.5	Mar 42	-	-	-	-	-	-
Ionia	1940	10.0	Mar 42	-	-	-	-	-	-
Jackson	1949	10.0	23 Mar 56	11.6	Jan 57	11.9	Jan 57	12.4	Jan 57
Lansing	1943	11.0 (2)	6 Nov 51	12.7	Nov 51	12.8	Nov 51	12.8	Nov 51
St. Johns	1949	10.0	7 Nov 51	11.9	Nov 51	11.9	Nov 51	12.8	Nov 51

(1) Maximum Recorded 24-Hour Snowfall, 14.0 inches

(2) Maximum Recorded 24-Hour Snowfall, 18.1 inches

TABLE C-6
GRAND RIVER BASIN, MICHIGAN
PROBABILITY OF SELECTED SNOW DEPTHS
U. S. WEATHER BUREAU STATIONS

Weather Station	Years Record	Snow Depth Inches	$\bar{t}$	Percent Probability of First Occurrence of the Snow Depth on or Before the Indicated Date 5%	10%	30%	70%	90%
Alma	68	1	Nov. 28	Nov. 1	Nov. 7	Nov. 20	Dec. 6	Dec. 19
		3	Dec. 13	Nov. 5	Nov. 14	Dec. 1	Dec. 25	Jan. 11
		6	Dec. 27	Nov. 19	Nov. 28	Dec. 18	Jan. 21	
		12	Jan. 27	Jan. 2	Jan. 12	Jan. 17		
Charlotte	45	1	Nov. 30	Nov. 5	Nov. 11	Nov. 22	Dec. 8	Dec. 19
		3	Dec. 17	Nov. 9	Nov. 18	Dec. 5	Dec. 30	Jan. 18
		6	Jan. 8	Nov. 21	Dec. 3	Dec. 28	Feb. 8	
		12	Jan. 24	Jan. 5	Jan. 17			
Grand Haven	33	1	Nov. 25	Oct. 31	Nov. 6	Nov. 17	Dec. 3	Dec. 14
		3	Dec. 5	Nov. 11	Nov. 17	Nov. 27	Dec. 13	Dec. 23
		6	Dec. 14	Nov. 13	Nov. 20	Dec. 4	Dec. 27	Jan. 16
		12	Jan. 4	Dec. 4	Dec. 13	Jan. 2		
Grand Rapids	64	1	Nov. 23	Oct. 28	Nov. 3	Nov. 15	Dec. 1	Dec. 13
		3	Dec. 6	Oct. 30	Nov. 6	Nov. 24	Dec. 18	Jan. 5
		6	Dec. 31	Nov. 12	Nov. 23	Jan. 22	Mar. 2	
		12	Jan. 15	Dec. 12	Dec. 27	Feb. 9		
Greenville	49	1	Nov. 29	Oct. 29	Nov. 5	Nov. 19	Dec. 9	Dec. 23
		3	Dec. 13	Nov. 5	Nov. 14	Dec. 1	Dec. 25	Jan. 11
		6	Jan. 3	Nov. 22	Dec. 3	Dec. 24	Jan. 29	
		12	Jan. 19	Dec. 17	Dec. 30	Jan. 3		
Hastings	66	1	Nov. 23	Oct. 30	Nov. 5	Nov. 16	Nov. 30	Dec. 11
		3	Dec. 11	Oct. 31	Nov. 8	Nov. 28	Dec. 24	Jan. 13
		6	Jan. 6	Nov. 19	Nov. 30	Dec. 26	Feb. 5	
		12	Jan. 17	Dec. 26	Jan. 10			
Howell	60	1	Nov. 30	Nov. 2	Nov. 8	Nov. 21	Dec. 9	Dec. 22
		3	Dec. 16	Nov. 3	Nov. 12	Dec. 2	Dec. 30	Jan. 19
		6	Jan. 8	Nov. 20	Dec. 2	Dec. 28	Feb. 9	
		12	Jan. 20	Dec. 23	Jan. 13			
Ionia	27	1	Nov. 29	Nov. 3	Nov. 9	Nov. 21	Dec. 7	Dec. 19
		3	Dec. 13	Nov. 9	Nov. 16	Dec. 2	Dec. 24	Jan. 9
		6	Jan. 12	Nov. 23	Dec. 5	Dec. 31	Feb. 10	
		12	Jan. 13	Dec. 18	Jan. 4			

$\bar{t}$ is the mean date for each desired snow depth.

TABLE C-6 (Cont'd)
GRAND RIVER BASIN, MICHIGAN
PROBABILITY OF SELECTED SNOW DEPTHS
U. S. WEATHER BUREAU STATIONS

Weather Station	Years Record	Snow Depth Inches	$\bar{t}$	Percent Probability of First Occurrence of the Snow Depth on or Before the Indicated Date 5%	10%	30%	70%	90%
Jackson	65	1	Nov. 26	Nov. 2	Nov. 9	Nov. 19	Dec. 3	Dec. 13
		3	Dec. 18	Nov. 4	Nov. 14	Dec. 4	Jan. 2	Jan. 25
		6	Jan. 12	Nov. 21	Dec. 4	Jan. 2	Feb. 24	
		12	Feb. 3	Jan. 17	Jan. 30			
Lansing		1	Nov. 25	Nov. 1	Nov. 6	Nov. 17	Dec. 3	Dec. 14
		3	Dec. 12	Nov. 9	Nov. 16	Dec. 1	Dec. 23	Jan. 7
		6	Jan. 4	Nov. 12	Nov. 24	Dec. 20	Jan. 27	Mar. 6
		12	Jan. 17	Dec. 22	Jan. 10			
Owosso		1	Nov. 30	Oct. 29	Nov. 5	Nov. 20	Dec. 10	Dec. 25
		3	Dec. 19	Nov. 9	Nov. 18	Dec. 6	Jan. 2	Jan. 22
		6	Jan. 8	Nov. 17	Nov. 29	Dec. 25	Feb. 4	
		12	Feb. 2	Jan. 5	Jan. 20	Mar. 26		
St. Johns	27	1	Dec. 2	Nov. 4	Nov. 11	Nov. 23	Dec. 11	Dec. 23
		3	Dec. 19	Nov. 10	Nov. 18	Dec. 6	Jan. 1	Jan. 19
		6	Jan. 5	Nov. 15	Nov. 28	Dec. 24	Feb. 4	
		12	Jan. 22	Dec. 24	Jan. 11			

$\bar{t}$ is the mean date for each desired snow depth.

TABLE C-7
GRAND RIVER BASIN, MICHIGAN
CALCULATED HAIL DAYS IN AN AVERAGE
20-YEAR PERIOD IN AND AROUND BASIN
U. S. WEATHER BUREAU STATIONS

Weather Station	Years of Hail Record	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Alma	15	0	1+	9+	14+	5+	4	3+	3	2	4	1	0	46
Charlotte	22	0	2-	5-	6+	5-	4-	2	6+	5-	9	3	0	47
Grand Haven	57	0	1	6-	7+	6-	3-	3	2	3	6-	5	*	40
Grand Rapids	62	*	1-	5	7	8	5	5-	2	3	4	2	*	42
Hastings	31	0	2	7+	9-	5-	7	3-	3	1+	3-	3-	1	44
Hillsdale	23	*	2-	4	9-	10+	8-	2-	3+	2-	5	2	1-	48
Lansing	56	0	2	5+	8	6	4-	3-	3-	1	2+	1	*	35
Muskegon	26	1-	1-	5-	8+	3	5-	4-	1-	4-	2-	2	1+	37
Newaygo	20	2	2	9	11	4	6	3	3	1	8	4	1	54

* indicates a very infrequent occurrence (less than once in 20 years)

11. HAIL

The formation of hail occurs from the rapid cooling of rising warm moist air, resulting in condensation, freezing, then freezing in an oscillating process whereby the small initial hailstones collect additional water droplets until the hailstones become too heavy and begin to fall. The process continues until the weight of the hailstone exceeds the uplift forces and the hailstone will fall to earth. The occurrence of this phenomenon is normally observed in the summer months of June, July and August. The interaction of the warm tropical air masses with the cool polar air masses associated with the formation of hail is greatest during these months. Hail storms are normally associated with thunderstorm activity and thus are very local in distribution. U. S. Weather Bureau (13) records for the years 1899-1938 indicate that the Grand River basin experienced hail from 2 to 3 days per year. Further data compiled by the U. S. Weather Bureau (14) for the years 1910-1943 indicate that the maximum number of occurrences of hail in the Basin for a year was six recorded at Lansing and Grand Rapids. In 1966 the Illinois State Water Survey collected and analyzed historical hail records from 225 U. S. Weather Bureau stations in Indiana, Michigan and Illinois, extending over the 1901-1965 period. The data were analyzed to develop mean seasonal and annual patterns of hail for these three states. Figure C-9 presents the average patterns of hail for the three primary seasons of hail activity resulting from this analysis. The number of hail days in an average 20-year period that have been calculated for the Michigan stations in and around the Grand River basin are shown in table C-7. (28)

12. NOTABLE STORMS OF THE BASIN

The Grand River basin experiences two types of storms, namely, the frontal type and the air mass type. Frontal-type storms develop along the interaction zones of cold polar and warm tropical air masses. Storms resulting from the interaction of air masses are frequently characterized by uniform rainfall of long duration over large areas. The severity of these storms depends on the strength of climatic components of the air masses. Normally, rainfall amounts are light to moderate. This type of storm occurs throughout the year. Convective air mass-type storms are normally characterized by very heavy rainfall amounts in short periods of time over relatively small areas. Thunder and lightning are normally associated with such storms. The Basin experiences (15) about 40 thunderstorms each year. These storms develop when quite humid air rises and creates an unstable condition within the air mass. As the individual air parcels rise, they expand and cool because of decreasing pressure. The cooling ultimately causes the water vapor to condense. The condensation is first characterized by a cloud formation. The process continues until the cloud can no longer maintain the condensed vapor and eventually releases it in the form of local rainfall. These storms normally occur during the warm summer

months of June, July, August and September. Notable storms that have produced significant hydrologic and hydraulic conditions within the Basin are described in the following sub-paragraphs.

a. Storm of 24-27 March 1904. The greatest flood of record for the Grand River basin, that of 28 March 1904, was the result of rapidly melting snow and light rainfall. Beginning around the middle of November, the winter season had been continuously cold with heavy snowfall amounts, especially in the eastern section of the Basin. Weberville had reported 110.4 inches of snowfall from November thru March. Nearly all the snowfall remained on the ground in the form of ice and heavily packed snow until the middle of March. Temperatures rose from the low 30's to the high 50's during the middle of the month. During 24-27 March, rainfall, which averaged about 0.9 inches over the Basin, accompanied the snow melt and produced serious flooding conditions. An isohyetal map of the 24-27 March storm is presented on plate C-11. Lines of equal depths of snowfall are also shown on plate C-11.

b. Storm of 5-6 June 1905. The second greatest Basin-wide flood of record, that of 9 June 1905, was produced by the maximum average rainfall recorded for the Grand River basin. Heavy rains, resulting from widespread thunderstorm activity on 5-6 June 1905, averaged about 4.6 inches over the Basin, with a maximum recorded precipitation of 6.12 inches at St. Johns, and a minimum amount of 2.53 inches recorded at Grand Haven. The center of the storm was located in the eastern portion of the Basin so that nearly all cities located along the Grand River experienced serious flooding. An isohyetal map of the 5-6 June storm is shown on plate C-10.

c. Storm of 31 August - 1 September 1914. The storm of 31 August - 1 September 1914 produced the greatest 24-hour period rainfall recorded in Michigan. The storm was centered at Cooper Center, Michigan, about 40 miles south of Grand Rapids. The maximum rainfall for the 24-hour period of 11.0 inches was recorded at Cooper Center. The storm was very localized for only 0.77 inches were recorded at Grand Rapids. The Grand River basin received an average amount of about 1.2 inches.

d. Storm of 17-19 August 1939. The storm of 17-19 August 1939 produced the second greatest 24-hour rainfall amount recorded in the Grand River basin when 5.69 inches fell at Hastings on 19 August 1939. Twenty miles to the east at Charlotte, only 1.25 inches of precipitation were recorded for the same period of time. Rainfall was light throughout the remainder of the Basin, with an average of about 2.0 inches. A minimum precipitation of 0.34 inches was recorded at Jackson. Runoff was light because of the high absorption capacity of the ground at the time.

e. Storm of 25-29 August 1940. The storm of 25-29 August 1940 produced the second greatest average Grand River basin rainfall of record. An average Basin rainfall of about 4.4 inches was computed, with a maximum recorded precipitation of 6.30 inches at Charlotte and a minimum recorded precipitation of 2.69 inches at Greenville. Crand River water levels at Grand Rapids rose about 8 feet from the storm. The coincidence of low river stages and high ground absorption capacity prevented flooding from this storm. An isohyetal map of this storm is presented on plate C-11.

f. Storm of 4-7 April 1947. The storm experienced 4-7 April 1947 in the Grand River basin was part of a State-wide storm which was centered just south of the Basin. An average Basin rainfall from this storm of about 2.4 inches was computed, with a maximum of 4.87 inches recorded at Jackson, and a minimum of 1.60 inches recorded at Grand Haven. About 9 inches of snow had fallen on the Basin two weeks previous to the storm. Temperatures remained at or near freezing until the first days of April, when they averaged in the low 40's. Temperatures rose sharply on the 5th to the high 60's. Serious flooding conditions prevailed in the Basin as a result of the heavy rainfall and accompanying snowmelt. About 90 percent of the recorded rainfall occurred within a 9-hour period. An isohyetal map of the 4-7 April 1947 storm is presented on plate C-12.

g. Storm of 19-21 March 1948. The storm of 19-21 March resulted in the last major flood experienced in the Grand River basin. The storm was generally uniformly distributed over the Basin, with a maximum precipitation of 3.11 inches recorded at Eaton Rapids, and a minimum of 0.50 inches recorded at McBride. An average Basin rainfall of about 2.4 inches was computed. Two weeks previous to the storm, about 10 inches of snow fell on the Basin. Temperatures remained below freezing until the middle of the month, when a moderate rise in temperature to the high 40's was experienced. This continued for about a week, when temperatures rose sharply to the 60's. As a result of the heavy rainfall and accompanying snowmelt, flooding conditions existed throughout the Basin. About 90 percent of the recorded rainfall occurred within a 12-hour period. An isohyetal map of the 19-21 March 1948 storm is shown on plate C-13.

h. Storm of 10-14 September 1950. The storm of 10-14 September was sporadic in character. The Grand River basin's maximum 96-hour duration rainfall amount of 6.70 inches occurred at St. Johns, while just 16 miles southwest, at Grand Ledge, only 0.30 inches of precipitation were recorded. Continuing southwest another 12 miles, at Charlotte, 6.49 inches were recorded. The rainfall over the entire Basin averaged about 2.5 inches. Runoff was insignificant because of the high absorption capacity of the ground at that time. About 90 percent of the recorded rainfall occurred within a 6-hour period.

i. Storm of 9-13 May 1956. During the period 9-13 May 1956, a storm center, which included severe thunderstorms accompanied by numerous tornadoes, occurred over the Grand River basin. Flood stages were reached on nearly all streams as a result of the generally heavy precipitation, which averaged about 3.1 inches over the whole Basin. The heaviest rainfall occurred at Grand Rapids, where 4.66 inches were recorded. The minimum precipitation of 2.19 inches was recorded at McBride. About 90 percent of the recorded rainfall occurred within an 18-hour period. An isohyetal map of the 9-13 May 1956 storm is shown on plate C-14.

13. DROUGHT PERIODS

Drought conditions are experienced when water supplies are not available over an extended period of time to meet the demands of plant and human activities (16). The water demands of crops and human activities are, in turn, dependent wholly or to a degree upon temperature, evaporation rates, character and condition of soil, the stage reached in the plant growth cycle, and the water supply needs for human activities. These numerous demands are not necessarily uniform throughout an area. What would constitute a drought in one locality would not necessarily be so designated in another. Water supplies are obtained from three sources, namely, surface waters, precipitation and groundwater, or may be made up almost entirely of only precipitation, surface water or groundwater. An indication of drought conditions may be determined for areas that are dependent entirely on precipitation by measuring deficiencies of precipitation. An indication of drought conditions may be determined for areas that are dependent entirely on groundwater or surface water by measuring deficiencies in streamflow. An indication of drought conditions when supplies are from precipitation surface water and groundwater would be a combination of deficiencies in the precipitation and streamflow. The severity of a drought may be indicated by the amount and duration of the deficiency. It is estimated that in the Grand River basin 95 percent of the water needs are supplied by precipitation. For practical purposes á measure of precipitation deficiencies could be utilized as a guide in measuring drought periods experienced in the Basin. The remaining 5 percent of water needs are supplied by wells and streamflow. Although comprising a small percent of the water supply, deficient periods experienced in these supplies would have severe effects on the Basin. With the exception of the Grand Rapids area, the Basin's entire polulation and industrial water needs are supplied from wells and streamflow (17). Drought conditions experienced from deficiencies in streamflow are discussed in detail in Appendix D of this study. The lowest annual precipitation that has occurred in the entire Basin during the period 1920 to 1963 was in 1930 when an average of only 20.55 inches of precipitation was computed, which is about 65 percent of the average annual rainfall. Studies presently being conducted for the State of Michigan by the U. S. Weather Bureau concerning drought measurements take into account nearly all climatological factors in determining drought

conditions (18). Research Report 78, dated February 1969, from the Michigan State University Agricultural Experiment Station, East Lansing, Michigan, contains monthly drought index values for years 1931 through 1967.

14. INTENSITY - DURATION - FREQUENCY

In the design of various facilities associated with water resources projects, it is necessary to select a design storm. The design storm is ordinarily dependent upon the frequency of the storm. The U. S. Weather Bureau (19) (20) (21) has developed information whereby, given a design frequency and a duration (from 20 minutes to 24 hours), the rainfall intensity may be obtained. The relationships were developed from annual series data collected by the U. S. Weather Bureau for the major cities: Grand Haven, Grand Rapids, Jackson and Lansing. Rainfall intensity-frequency curves for these cities are shown on figures C-4, 5, 6 and 7, respectively.

15. DEPTH - AREA - DURATION

The storm that could be expected from the most severe combination of critical meteorologic and hydrologic conditions that exist in the Grand River basin is referred to as the Maximum Probable Storm. Analysis of this storm is usually confined to the determination of spillway requirements for high dams. However, in unusual cases, it may constitute the design storm for local protection works where an exceptionally high degree of protection is advisable and economically obtainable. The storm resulting from the most severe combination of meteorologic and hydrologic conditions that are considered reasonably characteristic of the Grand River basin excluding extremely rare combinations is referred to as the Standard Project Storm. The flood estimate resulting from this storm represents a "standard" against which the degree of protection finally selected for a project may be compared with protection provided at similar projects at other localities. It may also constitute the design flood of a project where some small degree of risk is justified by hazards to life and high property values within the area to be protected. Flood discharge estimates from the Maximum Probable Storm and the Standard Project Storm are made from data developed from studies made by the U. S. Weather Bureau (22) and the Corps of Engineers (23). Maximum Probable Storm depth-area-duration relationships for the Grand River basin are presented on figure C-8. Standard Project Storm depth-area-duration relationships are estimated to be one-half those relationships developed for the Maximum Probable Storm (23/5).

SECTION V
TEMPERATURE

16. MEAN ANNUAL

Mean annual temperatures based on stations with 50 years of record or more (see table C-6) range from a high of 48.8° at Grand Rapids to a low of 47.0° at Grand Haven. Temperatures are referred to in degrees Fahrenheit (°F). The Grand River basin average annual temperature is 47.8° and the annual average of the daily maximum and the daily minimum temperatures are 57.7° and 37.9°, respectively. The lower maximum and higher minimum average annual temperatures are experienced in the western portion of the Basin. This is explained by the modifying effects of Lake Michigan in stabilizing temperature variations in the western section of the Basin. Annual means of maximum and minimum temperatures and mean temperatures of stations within the Basin are presented in table C-8. A map depicting the annual average temperatures of the Basin is shown on plate C-15.

March 1967

TABLE C-8

GRAND RIVER BASIN, MICHIGAN

ANNUAL AND MONTHLY NORMALS OF MAXIMUM, MINIMUM AND MEAN TEMPERATURES

U.S. WEATHER BUREAU STATIONS

Station	Years of Record	Jan. Mean	Jan. Max./Min.(2)	Feb. Mean	Feb. Max./Min.	Mar. Mean	Mar. Max./Min.	Apr. Mean	Apr. Max./Min.	May Mean	May Max./Min.	June Mean	June Max./Min.	July Mean	July Max./Min.	Aug. Mean	Aug. Max./Min.	Sep Mean	Sep Max./Min.	Oct. Mean	Oct. Max./Min.	Nov. Mean	Nov. Max./Min.	Dec Mean	Dec Max./Min.	Ann. Mean	Ann. Max./Min.
		°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
Charlotte	59	23.2	31.4/15.0	23.8	32.8/14.7	32.8	43.6/24.1	46.1	57.9/34.4	57.2	69.7/44.8	66.8	79.0/54.6	71.4	84.1/58.7	69.2	81.8/56.7	62.4	74.4/50.5	51.5	62.7/40.4	38.5	47.1/29.9	26.9	34.5/19.3	47.6	58.2/36.9
East Lansing Hort. Farm	7	20.9	28.0/13.8	22.8	31.0/14.6	32.7	41.2/24.2	47.0	58.1/36.0	58.4	70.3/46.5	66.7	78.8/54.7	70.4	82.4/58.5	69.2	80.8/57.6	62.9	74.3/51.5	52.6	63.4/41.9	39.2	47.2/31.2	25.9	33.2/18.6	47.4	57.4/37.4
Grand Haven	91	24.8	30.8/18.9	24.7	31.4/18.0	32.5	39.8/25.3	44.7	52.6/35.8	54.6	63.7/45.5	64.4	73.4/55.5	69.4	78.0/60.9	68.0	76.5/59.4	61.6	70.2/53.1	51.0	58.9/43.2	39.2	45.4/33.0	29.9	35.0/23.9	47.0	54.6/39.4
Grand Rapids	58	24.6	30.8/18.3	24.6	31.6/17.5	34.0	42.1/26.0	46.7	56.4/37.0	58.1	68.6/47.6	68.2	78.9/57.4	72.9	83.4/62.4	70.8	81.3/60.4	63.5	73.5/53.5	52.2	61.3/43.2	39.4	46.1/32.6	28.5	34.2/22.8	48.8	57.4/40.2
Greenville	49	23.2	30.7/15.8	24.0	32.3/15.7	32.8	42.0/23.5	46.0	57.3/34.8	57.3	69.5/45.1	67.3	79.6/55.1	72.1	84.5/59.7	68.8	81.7/57.8	62.1	73.5/50.7	51.5	62.2/40.8	38.2	45.8/30.6	27.3	34.1/20.6	47.6	57.8/37.5
Hastings	66	23.6	31.4/15.7	24.2	33.0/15.4	33.8	43.4/[illegible]	47.2	59.6/34.9	57.8	70.8/44.9	67.5	80.2/54.8	71.8	84.8/58.8	69.7	82.6/56.7	62.7	75.1/50.3	51.5	63.0/40.0	38.6	46.8/30.4	27.4	34.7/20.2	48.0	58.8/37.2
Ionia	70	23.7	30.6/14.9	24.8	33.8/15.7	33.5	43.5/23.6	47.4	59.6/35.2	57.3	70.1/44.6	67.5	80.4/54.6	71.4	84.6/58.2	69.7	82.6/56.8	62.0	74.9/49.2	52.3	64.8/39.9	38.8	47.3/30.3	27.7	35.2/20.2	47.9	59.0/36.9
Jackson	67	24.1	31.8/16.5	25.0	33.4/16.5	34.8	44.3/25.3	47.3	58.6/36.1	58.5	70.6/46.4	68.0	80.2/55.9	72.8	85.2/60.4	70.5	82.7/58.3	63.7	75.7/51.8	52.5	63.6/41.4	38.9	47.0/30.8	27.7	34.7/20.7	48.6	59.0/38.3
Lansing	89	22.7	29.9/14.6	23.1	31.1/15.1	32.0	40.8/23.2	45.5	55.8/35.2	56.7	68.0/45.4	66.9	8.0/55.8	71.2	82.9/59.5	69.0	80.7/57.3	61.5	73.0/50.0	49.9	60.2/39.6	37.0	43.9/30.1	26.6	33.4/19.8	46.9	56.7/37.1
St. Johns	41	23.1	30.7/15.5	23.2	32.0/14.5	32.6	42.1/23.0	46.4	58.3/34.5	57.2	69.4/45.0	67.5	79.6/55.4	71.6	84.1/59.2	69.5	81.9/57.1	62.5	74.5/50.6	51.4	62.5/40.4	38.3	46.2/30.4	27.6	34.7/20.4	47.6	58.0/37.2
Grand River Basin (1)		23.5	30.9/16.2	24.0	32.2/15.9	33.4	42.4/24.4	46.4	57.2/35.3	57.4	69.1/45.6	67.0	78.9/55.1	72.1	83.7/60.6	69.7	81.4/58.0	62.4	73.8/51.1	51.5	62.0/41.0	38.6	46.2/31.0	27.5	34.2/20.8	47.8	57.7/37.9

(1) Grand River Basin averages based on stations with 50 years of record or more, near and in the Basin.

(2) Mean monthly maximum temperatures / Mean monthly minimum temperatures

17. MONTHLY DISTRIBUTION OF TEMPERATURES

Average monthly temperatures for the Grand River basin range from a high of 72.1° in July to a low of 23.5° in January. The monthly average of the daily maximum temperatures for the Grand River basin ranges from 83.7° in July to 30.9° in January. The monthly average of the daily minimum temperatures ranges from 60.6° in July to 15.9° in February. The highest monthly average of the daily maximum temperature is 85.2° in July at Jackson while the lowest monthly average of the daily minimum temperature is 13.8° at East Lansing during January. The effects of Lake Michigan on monthly temperatures are evident for the western section of the Basin. Average maximum temperatures are up to 5° cooler in the western sections compared to those in the eastern portion of the Basin, while average minimum temperatures are up to 5° warmer for the western section of the Basin, compared to those in the eastern portion of the Basin. Monthly normals of maximum, minimum and mean temperatures for stations located within the Basin are shown in table C-7.

18. DIURNAL VARIATION OF TEMPERATURES

The maximum recorded temperature in the Grand River basin of 109° was reported at Hastings 14 July 1936. The minimum temperature in the Basin of 33° below zero was recorded at Lansing in January 1875. U. S. Weather Bureau records from 1900 to the present indicate that daily temperatures approach record maximum and minimum values quite often throughout any given year. Maximum temperatures of over 100° are not uncommon in the course of a year, as are temperatures below zero. Daily variations of temperatures are greatest in the eastern section of the Basin, where they vary about 25° in the summer and about 15° in the winter. Daily variations of temperatures in the western portion of the Basin are from 20° in the summer to 10° in the winter. This difference is again explained by the stabilizing effect of Lake Michigan on temperatures. Maximum and minimum recorded temperatures for stations located within the Basin are presented in table C-9.

TABLE C-9
GRAND RIVER BASIN, MICHIGAN
MAXIMUM AND MINIMUM RECORDED TEMPERATURES
U.S. WEATHER BUREAU STATIONS

March 1967

RECORDED TEMPERATURE EXTREMES

Station	Record Date	Jan. Max. Min. °F	Jan. Date/Yr.	Feb. Max. Min. °F	Feb. Date/Yr.	Mar. Max. Min. °F	Mar. Date/Yr.	Apr. Max. Min. °F	Apr. Date/Yr.	May Max. Min. °F	May Date/Yr.	June Max. Min. °F	June Date/Yr.
Charlotte	1903	65 -26	26/44 15/27	67 (1) -31	22/30 10/12	87 -12	* 8/60	87 4	* *	92 23	18/62 4/26	101 32	20/53 *
East Lansing Hort. Farm	1957	52 -14	13/61 24/63	55 -17	19/61 2/59	76 -8	30/63 2/62	84 21	23/60 6/60	90 27	29/62 1/63	94 33	17/57 3/57
Grand Haven	1873	63 -14	26/50 1912	62 -25	1921 1899	79 - 8	27/45 3/43	85 9	30/42 1874	94 25	31/34 4/26	96 34	1/34 4/45
Grand Rapids	1887	66 -22	25/50 30/51	67 -24	22/30 1899	82 -5	27/45 3/43	90 13	1899 1/54	98 21	1895 1903	102 35	20/53 4/45
Greenville	1915	64 -22	26/50 15/63	67 -25	22/30 12/14	80 -12	29/63 3/43	88 7	* *	92 23	18/62 4/26	101 34	1/34 2/56
Hastings	1899	66 -24	25/50 23/48	67 -31	22/38 1899	92 -16	22/38 3/43	92 9	* *	95 20	31/34	104 32	20/53 2/56
Ionia	1941	69 -25	20/52 15/63	68 -31	15/54 1899	81 -15	27/45 2/62	87 12	23/60 3/54	91 22	21/62 9/47	102 31	19/53 6/58
Jackson	1897	67 -20	25/50 *	64 -21	15/54 10/12	83 -6	22/38 28/34	88 9	6/29 *	99 20	* *	102 33	1/34 3/26
Lansing	1874	65 -26	25/50 1887	66 -33	22/30 1875	82 -14	1910 1877	88 3	1915 1874	96 21	1874 1874	99 33	1895 1875
St. Johns	1912	64 -19	26/44 30/51	61 -22	26/44 1899	80 -14	24/39 5/48	87 10	* 3/54	95 23	* 11/49	100 29	20/53 8/49
Grand River Basin		69 -26	20/52 15/27	68 -33	15/54 1875	87 -16	* 3/43	92 3	* 1874	98 20	1895 *	104 29	20/53 8/49

Station	Record Date	July Max. Min. °F	July Date/Yr.	Aug. Max. Min. °F	Aug. Date/Yr.	Sept. Max. Min. °F	Sept. Date/Yr.	Oct. Max. Min. °F	Oct. Date/Yr.	Nov. Max. Min. °F	Nov. Date/Yr.	Dec. Max. Min. °F	Dec. Date/Yr.
Charlotte	1903	106 39	14/36 9/63	101 36	* 22/52	100 25	2/53 21/56	91 14	* 25/60	79 -9	1/50 23/56	66 -23	4/41 *
East Lansing Hort. Farm	1957	94 43	2/63 10/63	91 39	26/59 18/63	94 28	8/60 28/57	87 19	6/63 25/60	72 0	2/61 30/58	59 -14	4/62 31/63
Grand Haven	1873	101 40	21/34 1873	95 39	18/55 29/34	94 30	15/39 1879	84 20	4/51 1887	75 -7	3/61 25/50	63 -12	3/51 1884
Grand Rapids	1887	108 45	13/36 70/63	102 37	1918 1890	98 29	1913 24/50	89 17	1887 1897	81 -10	1/50 25/50	63 -11	6/51 31/46
Greenville	1915	108 42	13/36 4/63	104 39	19/55 *	101 27	1/53 *	87 12	15/47 *	80 -3	1/50 25/50	62 -16	3/51 18/26
Hastings	1899	109 36	14/36	105 30	* *	97 25	6/54 *	90 12	4/51 *	82 -7	1/50 25/50	65 -19	4/41 18/26
Ionia	1941	101 37	26/41 4/63	103 38	5/47 18/63	97 21	2/53 29/42	88 16	4/51 25/60	79 -7	1/50 30/58	65 -13	4/41 31/62
Jackson	1897	105 41	14/36 *	103 37	* 21/50	101 *	* 29/42	91 16	* *	79 -5	1/50 25/50	65 -13	4/41 *
Lansing	1874	102 42	24/34 11/45	102 30	1918 1869	99 21	1894 1899	90 7	1898 1899	79 -4	1/50 1880	70 -25	1875 1884
St. Johns	1912	101 39	* 11/45	102 39	6/47 24/51	99 27	1/53 29/51	89 14	3/53 *	79 -6	1/50 26/49	65 -14	4/41 *
Grand River Basin		109 36	14/36 *	105 30	* 1869	101 21	* 29/42	91 7	* 1869	82 -10	1/50 25/50	70 -25	1875 1884

* Recorded Prior to 1925

(1) Underlined values indicate Station Maximum or Minimum Temperatures and date

19. FREEZE - GROWING SEASON

The occurrence of a killing frost varies significantly in the Grand River basin (24). The western section of the Basin averages about 23 weeks of temperatures above freezing, while the eastern section averages about 21 weeks above freezing. The difference in frost-free days is explained by the stabilizing effects of Lake Michigan on temperatures. The difference of two weeks in freezing temperature periods is distributed to one week in the spring and one week in the fall. The average date of the last spring occurrence of frost in the Basin usually occurs during the first week of May, and the average date of the first fall occurrence during the first week of October. Freeze data for Grand Haven, Lansing, Jackson, Greenville, Grand Rapids, Charlotte and Hastings are presented in table C-10.

Table C-10

GRAND RIVER BASIN, MICHIGAN
FREEZE DATA

LOCATION	DATES OF RECORD	MEAN DATE LAST SPRING OCCURRENCE					MEAN DATE FIRST FALL OCCURRENCE					DAYS BETWEEN MEAN DATES				
	Years	16^oF or below	20^oF or below	24^oF or below	28^oF or below	32^oF or below	32^oF or below	28^oF or below	24^oF or below	20^oF or below	16^oF or below	16^oF	20^oF	24^oF	28^oF	32^oF
Grand Haven	1921-1963	14 Mar	23 Mar	1 Apr	18 Apr	2 May	13 Oct	3 Nov	17 Nov	29 Nov	7 Dec	268	251	230	199	164
Lansing	1921-1963	18 Mar	26 Mar	7 Apr	23 Apr	6 May	7 Oct	26 Oct	7 Nov	20 Nov	28 Nov	255	239	213	186	154
Jackson	1921-1963	18 Mar	26 Mar	10 Apr	22 Apr	9 May	5 Oct	20 Oct	6 Nov	18 Nov	26 Nov	253	237	209	181	149
Greenville	1921-1951	20 Mar	30 Mar	13 Apr	18 Apr	9 May	6 Oct	22 Oct	28 Oct	15 Nov	26 Nov	251	230	198	187	150
Grand Rapids	1921-1951	10 Mar	20 Mar	29 Mar	12 Apr	25 Apr	27 Oct	9 Nov	19 Nov	1 Dec	7 Dec	272	256	235	211	185
Charlotte	1921-1951	21 Mar	1 Apr	15 Apr	29 Apr	12 May	5 Oct	22 Oct	5 Nov	15 Nov	26 Nov	250	228	204	176	146
Hastings	1921-1951	21 Mar	31 Mar	18 Apr	1 May	15 May	3 Oct	17 Oct	5 Nov	15 Nov	25 Nov	249	228	200	169	131

SECTION VI
WINDS, CLOUDINESS AND HUMIDITY

20. PREVAILING WINDS

Prevailing winds in the Grand River basin are from the south and west, at an average speed of about 9.5 MPH. The earth's temperature and pressure gradients and rotation create the prevailing westerly winds associated with the mid-latitudes. The fastest (excluding tornadoes) wind speed recorded in the Basin of 65 MPH was recorded at Grand Rapids, from the southwest, November 1952. Pertinent wind data for Grand Rapids and Lansing are presented in table C-11.

Table C-11
GRAND RIVER BASIN, MICHIGAN
WIND, CLOUDINESS AND HUMIDITY

March 1967

WIND

Station	Years of Record	Annual Mean Hourly Wind Speed	Prevailing Direction Range	Prevailing Wind Direction	FASTEST WIND SPEED Speed	Direction	Date
		MPH			MPH		
Grand Rapids	15	10.0	WNW-SSW	W	65	SW	Nov. 1952
Lansing	27	8.8	NW-S	SW	63	SE	Jun. 1963

CLOUDINESS

Station	Years of Record	Percent of Possible Sunshine - Sunrise to Sunset: Ann. %	Max. %	Max. Mo.	Min. %	Min. Mo.	AVERAGE ANNUAL NUMBER: Clear Days	Partly Cloudy Days	Cloudy Days
Grand Rapids	13	50	69	July	26	Dec.	72	95	198
Lansing	49	52	72	July	28	Dec.	93	109	163

HUMIDITY

Station	Years of Record	Mean Annual Relative Humidity: 1:00 A.M. %	7:00 A.M. %	1:00 P.M. %	7:00 P.M. %	Mean Max. %	Mo.	Time	Mean Min. %	Mo.	Time
Grand Rapids	24	82	83	61	67	87	Aug thru Oct.	7:00 A.M.	51	July	1:00 P.M.
Lansing	15	80	82	60	65	90	Sept.	7:00 A.M.	51	July	1:00 P.M.

21. TORNADOES

The occurrence of tornadoes within the Grand River basin has varied in severity, frequency, and location. Tornadoes are characterized by a dark cloud which descends toward the earth with a funnel-like shape marking a vortex, which may or may not touch the ground (25). They are usually attended by heavy precipitation, thunder, and hail. The destructive force of a tornado is caused by a partial vacuum created by spiraling winds which are estimated to range from 200 MPH to 500 MPH. They usually travel from the southwest direction at a rate of 20 to 40 MPH and have an average width of about 350 yards and a median length of five miles. Tornadoes normally occur during the warm spring and summer days. They normally develop after the hottest time of day. About 42 percent of the tornadoes occur from 3:00 P.M. to 7:00 P.M. The Weather Bureau has reported the occurrence of 38 tornadoes within the Basin since 1926 through 1965. The greater portion of these tornadoes have been reported since 1950. This is explained by the greater efficiency in reporting tornado activity as a result of the greater population density in the Basin since 1950. The Palm Sunday tornado outbreak of April 1965 was the most disastrous reported tornado in the Basin. It affected six midwestern states and was the nation's worst tornado disaster in 40 years. At least 37 separate tornadoes were identified over a six-state area encompassing Iowa, Illinois, Wisconsin, Michigan, Indiana and Ohio. Three meteorological conditions, necessary for tornado formations, converged over the upper Mississippi Valley on Sunday, 11 April 1965. Warm, moisture-laden air streamed northeastward from the Gulf of Mexico, ahead of a fast-moving, low pressure area. Approaching equally fast from the west was a mass of relatively dry cooler air. One facet of the outcome, as the outbreak of tornadoes and storms developed, was to sweep and destructively scourge the entire Basin with tornadoes (29). The paths of known tornadoes within the Basin are shown on plate C-16. The greater portion of reported tornado activity is near the cities. This is to be expected because of the greater population density than in the rural areas that would report tornado activity.

22. PERCENT OF CLOUDINESS

The percent of cloudiness is a ratio of how much cloud cover the Basin has experienced compared to the total sky cover. The Basin averages about 50 percent possible sunshine with very little variation through the Basin. The eastern portion experiences about 21 more clear days than does the western portion. This difference is attributed to the effects of Lake Michigan, especially in the winter months when air masses over the relatively warm surface of Lake Michigan pick up additional moisture and are made more unstable by heating from the Lake. Pertinent information regarding cloudiness at Grand Rapids and Lansing is presented in table C-11.

23. RELATIVE HUMIDITY

Relative humidity is a ratio of the amount of moisture in a given volume of air compared to the amount that volume could contain if it were saturated expressed as a percent. Relative humidity at Lansing ranges from a mean maximum of 90 percent in September to a mean minimum of 51 percent in July. Relative humidity is greatest during the early morning hours and generally lowest during the afternoon hours hottest time of the day because, as the temperature increases, the capacity of the air for moisture also increases, thus giving a lower relative humidity. Pertinent data on humidity at Grand Rapids and Lansing are shown in table C-11. The occurrences of fog within the Basin normally occur in the spring months of April, May and June, and in the fall months of September and October. The western section of the Basin experiences more fog than the interior section of the Basin. This difference is explained by the Lake Michigan effects. During the spring months, warm moist air masses are cooled by the Lake Michigan waters. In the fall months the relatively warm Lake waters heat air masses which, in turn, are cooled by the colder land areas. U. S. Weather Bureau records indicate that dense fog (visibility less than 1/4 mile) (26/27) occurs about 10 to 20 days per year for the west coast section of the Basin, whereas, from 5 to 10 days per year occur within the interior Basin.

SECTION VII
PROJECTED HYDROCLIMATIC DATA NEEDS

24. PRESENT AND FUTURE CLIMATOLOGICAL DATA NEEDS

Needs for climatological data to be utilized in forecasting the possible occurrence of natural phenomenon are dependent on the degree of significance that the occurrence frequency and severity of this phenomenon would have on an area's economy, life and health. Projected needs for hydroclimatic data are those needs which are not presently provided. There are three natural phenomena that occur in the Grand River basin that have significant effects on the Basin's economy, life, and health, namely, rainfall, winter storms and tornadoes. The present methods of forecasting these phenomena, and the projected needs, are discussed in the following paragraphs.

25. The Weather Bureau at Washington, D. C., receives climatological data from throughout the world in analyzing expected weather conditions. This analysis is transmitted by teletype and facsimiles to the U. S. Weather Bureau at Chicago, Illinois. Utilizing data received from Washington, D. C. as a guideline, and information received from Weather Bureau stations in Michigan, and data received from meteorological satellites, the Weather Bureau prepares at Chicago the state-wide forecast for Michigan and transmits it to Lansing and Grand Rapids by teletype. State-wide forecasts for Michigan are subdivided into seven sections. The Grand River basin is located within

four sections, namely, the Southwest, West Central, Central, and South Central sections. Except on rare occasions, these forecasts are not altered by the Weather Bureau stations at Grand Rapids or Lansing.

26. The extent and severity of floods and drought periods depends directly on the amount and occurrence of precipitation. A concise forecast of the occurrence of excessive or subnormal rainfall would greatly reduce the effects of an occurrence of this phenomenon. At present, the occurrences of rainfall are forecast for the State of Michigan by the U. S. Weather Bureau at Chicago. Characteristics associated with a rainfall forecast by the Chicago Weather Bureau are the time of occurrence (24-hour period), area distribution (by sectional classification), and a general statement as to the amount of rainfall expected. The Weather Bureau stations at Lansing and Grand Rapids issue forecasts for their vicinity within a 25-mile radius. The entire Basin has radar coverage from Chicago, Detroit and Muskegon Weather Bureau stations. This coverage enables the Weather Bureau to maintain a continuous observation of aerial distribution and movement. Rainfall forecasts are not presently utilized in flood or drought forecasting. Flood forecasts are presently made based on existing conditions. Whenever measured rainfall amounts exceed 0.5 inches they are telephoned to the Lansing or Grand Rapids River Forecast District. In addition to rainfall amounts, Basin conditions such as snow cover and soil perviousness and stream gage readings are also telephoned. The Lansing District is responsible for flood forecast on the Grand River from Jackson to Grand Ledge and the Red Cedar at East Lansing. The Grand Rapids District is responsible for the Grand River downstream of Grand Ledge to Grand Rapids. Projected climatological needs are contingent on possible inclusion of reservoirs in the comprehensive basin development plan. Effective and safe operation of these reservoirs would be dependent on utilizing forecasted and actual basin climatological data. Forecasted rainfall may be improved by knowledge of the rainfall intensity. Radar equipment is presently being developed and tested for this purpose. Determination of actual Basin climatological conditions may be improved by establishing more precipitation stations. Drought forecast cannot be made with present knowledge and technology. The U. S. Weather Bureau at Washington, D. C., issues 30-day forecasts which consist of general statements of above or below normal rainfall amounts. These forecasts are issued every two weeks so that in effect 30-day forecasts are only two-week forecasts.

27. Winter storm forecasts are made in a manner similar to rainfall forecasts. The storm forecast would consist of the amount of snowfall expected, the possibilities of freezing rain or ice conditions, and the areal distribution expected of the storm. Projected climatological needs may consist of improved knowledge of the snowfall intensities. Radar equipment presently being developed and tested for measuring rainfall intensity may also be utilized to measure snowfall intensity.

28. Tornado forecasts are prepared for the State of Michigan by the Weather Bureau in Kansas City, Kansas. Two types of forecasts are issued, namely, a "tornado watch" and a "tornado warning". A "tornado watch" is issued when weather conditions are favorable for tornado development. A "tornado warning" is issued when a tornado has been sighted. Radar coverage of the Basin is the most valuable source of tornado detection. Although radar cannot detect the occurrence of a tornado, it does determine the locale and severity of storm centers from which tornadoes normally develop. Research presently being done by the U. S. Weather Bureau in the mid-American states on the phenomenon of tornadoes should provide valuable information concerning the development of tornadoes from which possible new and/or more climatic data may be acquired for forecasting the occurrence of a tornado.

29. CONTROLLED WEATHER

The U. S. Weather Bureau has been involved in research on controlled weather for years. The complexity and magnitude of weather makes it difficult to develop a scientific and practical approach to controlling weather. Numerous attempts on controlling weather have been tried by private individuals and institutions, and Federal supported agencies such as the Army, Navy and Air Force. These attempts have been both successful and unsuccessful. Successful control of weather phenomenon have normally been confined to control for a relatively small area. A Basin-wide approach to possible controlled weather does not appear practical at this time.

30. CRITERIA TO ESTABLISH WEATHER BUREAU STATIONS

In 1954 the Weather Bureau developed a grid system which would establish one Weather Bureau station for every 600 square miles. This grid system is supplemented as needs for additional information become apparent. Most of these stations, called cooperative stations, are operated from donated time or at nominal costs for special projects. First order stations are established when the cost of equipment, maintenance and compilation of data are justified by the need for detailed weather information. The Michigan Water Resources Commission, in cooperation with the U. S. Weather Bureau, U. S. Geological Survey and Michigan State University, is presently engaged in a study within the Red Cedar basin whereby the effectiveness of areal coverage of rain gages may be determined. Results of this study will be an aid in determining the number of rain gages that may be needed for improving the flood forecasting system for the Basin.

31. ORGANIZATION OF WARNING SYSTEM FOR OCCURRENCE OF A NATURAL DISASTER.

The issuance of a forecast of the possible occurrence of a natural disaster is the responsibility of the U. S. Weather Bureau. The responsibility to warn or alert the Federal, military and civilian authorities, State officials and the civilian population of this forecast is the responsibility of the Office of Civil Defense. The Office of Civil Defense

issues these forecasts to the Red Cross, Radio, Television, Press, Corps of Engineers, Michigan State Police and other Federal, State and local agencies. The main responsibility of the Red Cross is to provide food, shelter and medical assistance to disaster areas. Radio, Television and Press responsibilities are to inform the civilian population of the possible occurrence of a natural disaster and the precautions that should be taken against the disaster. The Corps of Engineers' chief responsibility is during flood disasters. Emergency flood control activities including flood emergency preparation, flood fighting and rescue work during the period of actual emergency, and post-flood repair and restoration of flood control works are the main responsibilities of the Corps of Engineers. When requested by the Office of Civil Defense, the Corps of Engineers also assesses damages to Government-owned facilities resulting from disasters including tornado action. The Michigan State Police responsibilities consist mainly of assisting in informing the civilian population of a possible occurrence of a natural disaster, isolating a disaster area, and providing uninterrupted access to and from a disaster area for rescue, relief and aid personnel.

32. The Natural Disaster warning organizational system has never seriously been tested in the Grand River basin. The occurrence of natural disasters in the Basin have been confined to small areas and relatively minor severity. Areas where the frequency and severity of natural disasters are high have been served effectively by this type of organized warning system.

SECTION VIII
BIBLIOGRAPHY

1. Linsley, Kohler, Paulus, Applied Hydrology, pp. 5-17, McGraw-Hill, New York, (1949).

   Descriptions of factors that affect an area's climate.

2. U. S. Weather Bureau, Monthly Climatological Data for Michigan, U. S. Government Printing Office, Washington, D. C., (1897-to Present).

   Currently these issues contain a general data table, a daily precipitation table, a daily temperature table, a supplemental table of wind, relative humidity, etc., for selected stations, a table of snowfall and snow on ground, evaporation and wind table, daily soil temperature, and a station index table. Monthly and seasonal snowfall, and heating degree days are published in the July issue only. Past issues have varied to some degree in the type and amount of data published.

3. U. S. Weather Bureau, Hourly Precipitation Data for Michigan, U. S. Government Printing Office, Washington, D. C., (1948).

   The monthly issue presents daily and hourly precipitation data from stations equipped with automatic recording gages. The annual issue contains monthly and annual totals of precipitation.

4. U. S. Weather Bureau, Local Climatological Data for Grand Rapids, U. S. Government Printing Office, Washington, D. C., (1930-to Present).

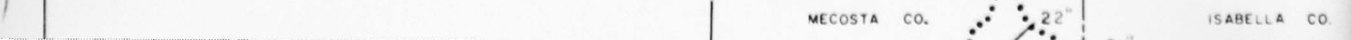
   The monthly issue presents basic climatological data, with a table of hourly precipitation for the month for Grand Rapids.

5. U. S. Weather Bureau, Local Climatological Data for Lansing, U. S. Government Printing Office, Washington, D. C., (1930-to Present).

   The monthly issue presents basic climatological data, with a table of hourly precipitation for the month for Lansing.

6. U. S. Weather Bureau, Annual Climatological Data for Michigan, U. S. Government Printing Office, Washington, D. C., (1924-to Present).

   The annual issue presents tables as follows: monthly and average temperatures and departures from normal; monthly and annual total precipitation and departures from normal; temperature extremes and freeze data; monthly and annual total evaporation and wind movement; monthly and annual average and extreme soil temperatures



at selected depths, plant-available water in soil, deficit and precipitation, together with the related description of the soil moisture sites.

7. U. S. Weather Bureau, *Climate of Michigan by Stations*, 156 pp., Michigan Weather Service, East Lansing, (February 1963).

This issue presents a "means and extremes" table, and sequential tables of monthly average temperature and total precipitation. Included is a narrative summary of the local climate and a history of changes in station location and related information.

8. U. S. Weather Bureau, *Climatic Summary of the United States - Michigan*, U. S. Government Printing Office, Washington, D. C. Three dates of Issue, (1930, 1952 and 1960).

These issues present, by stations, sequential tables of monthly and annual values of total precipitation, mean monthly and annual snowfall amounts, mean temperatures, mean maximum and mean minimum temperatures, and highest and lowest temperatures. The 1930 edition also presented maximum hourly precipitation amounts for selected stations.

9. U. S. Weather Bureau, *Daily and Hourly Precipitation for Region 3 - Ohio River*, U. S. Government Printing Office, Washington, D. C., (1940-1948).

The monthly issue presented the daily and hourly precipitation data from stations equipped with automatic recording gages.

10. U. S. Weather Bureau, *Michigan Snow Depths*, Michigan Weather Service, East Lansing, 14 pp., (June 1964).

Pamphlet describing the variation in Michigan Snow Depths by narration, maps and statistics.

11. U. S. Weather Bureau, *Monthly Storm Data for Michigan*, U. S. Government Printing Office, Washington, D. C.,(1959-to Present).

This publication presents a chronological listing of occurrences of storms and unusual weather phenomena, together with data on the paths of individual storms, deaths, injuries, and property damage resulting therefrom, and a brief narrative of associated details attending each occurrence.

12. U. S. Weather Bureau, *Frequency of Maximum Water Equivalent of March Snow Cover in North Central United States*, Technical Paper No. 50, 24 pp., U. S. Government Printing Office, Washington, D.C., (1964).

This paper presents generalized information from which maximum water equivalent values of snow on the ground for the first and second halves of March could be developed for any area north of 40°N and between 80° and 105°W.

13. U. S. Department of Agriculture, Climate and Man, p. 730, U. S. Government Printing Office, Washington, D. C., (1941).

A map depicting the occurrence of hail throughout the U. S. on an average day per year basis during the period 1899-1938.

14. U. S. Weather Bureau, Thunderstorm Rainfall, Hydrometeorological Report No. 5, Part I, pp. 149-150, Waterways Experiment Station, Vicksburg, Mississippi, (1947).

A table indicating the maximum number of occurrences of hail within one year for the period 1910-1943 for selected Weather Bureau stations throughout the U. S.

15. U. S. Weather Bureau, Mean Number of Thunderstorm Days in the U.S. Technical Paper No. 19, 22 pp., U. S. Government Printing Office, Washington, D. C., (1952). (Now out of print).

This paper presents tables of average monthly, seasonal, and annual number of thunderstorm days in the U. S. It also includes charts depicting the monthly distribution of days with thunderstorms.

16. Hoyt, J. C., Drought of 1936, U. S. Geological Survey, Water Supply Paper No. 820, p. 1, U. S. Government Printing Office, Washington, D. C., (1938).

A discussion of the significance of droughts in relation to climate is presented.

17. U. S. Army, Corps of Engineers, Grand River Data Book, pp. B-18 to B-25, U. S. Army Engineer District, Detroit.

Data book lists the water supply facilities for all municipalities in the Grand River basin.

18. U. S. Weather Bureau, Meteorological Drought, Research Paper No. 45, 58 pp., U. S. Government Printing Office, Washington, D. C., (February 1965).

This paper provides a technique to measure the degree of drought an area experiences.

19. U. S. Weather Bureau, Maximum Recorded U. S. Point Rainfall for 5 Minutes to 24 Hours, Technical Paper No. 2, 56 pp., U. S. Government Printing Office, Washington, D. C., (1963).

This paper provides maximum recorded point rainfalls for 5, 10, 15, 30 and 60 minutes, and 2, 3, 6, 12 and 24-hour durations for selected stations throughout the U. S.

20. U. S. Weather Bureau, Rainfall Intensity-Duration-Frequency Curves, Technical Paper No. 16, 53 pp., U. S. Government Printing Office, Washington, D. C., (December 1955).

This paper presents rainfall intensity-duration curves for durations of 5 minutes to 24 hours, and return periods of 2, 5, 10, 25, 50, and 100 years for selected stations throughout the U. S.

21. U. S. Weather Bureau, Rainfall-Intensity-Frequency Regime - Part 5 - Great Lakes Region, Technical Paper No. 29, 31 pp., U. S. Government Printing Office, Washington, D. C., (February 1960).

This paper provides a technique to develop rainfall-intensity-duration frequency relationships within the Great Lakes Region based on precipitation data for numerous U. S. Weather Bureau stations within the Great Lakes region.

22. U. S. Weather Bureau, Seasonal Variation of the Probable Maximum Precipitation East of the 105th Meridian for Areas 10 to 1,000 Square Miles and Durations of 6, 12, 24 and 48 Hours. Hydrometeorological Report No. 33, 58 pp., U. S. Government Printing Office, Washington, D. C., (April 1956).

This paper depicts probable maximum rainfall amounts for each month and an all-season period throughout the U. S. for various size drainage areas and duration of 6, 12, 24 and 48 hours.

23. U. S. Army, Corps of Engineers, Standard Project Flood Determinations, Civil Engineer Bulletin No. 52-8, 19 pp., Office of the Chief of Engineers, Washington, D. C., (June 1964).

This paper describes and illustrates a procedure to determine the rainfall amounts associated with the occurrence of the most severe combination of meteorologic and hydrologic conditions considered reasonable of the geographic region.

24. Agricultural Experiment Station, Michigan Freeze Bulletin, Research Report 26, Farm Science, 40 pp., Michigan State University, East Lansing, (No date).

This paper provides freeze data such as number of occurrences, frequency of occurrences, and information on the relative susceptibility of various types of plant growth at certain critical temperatures.

25. U. S. Weather Bureau, Tornado Occurrences in the U. S., Technical Paper No. 20, 17 pp., U. S. Government Printing Office, Washington, D. C., (1960).

This paper describes in detail, the nature of the formation of tornadoes, characteristics of tornadoes, and their occurrence from 1916 to 1958 throughout the U. S. Numerous tables, charts and statistics are also provided.

26. U. S. Weather Bureau, Climatology and Weather Services of the St. Lawrence Seaway and Great Lakes, Technical Paper No. 35, 75 pp., U. S. Government Printing Office, Washington, D. C., (1959).

This paper presents climatological data, and weather services available for the Great Lakes and the St. Lawrence Seaway.

27. Haschke, R. E., editor, Glossary of Meteorology, American Meteorological Society, 638 pp., Boston, Massachusetts, (1959).

Comprehensive glossary of all meteorology and related phenomena. It is the source of most definitions presented in the Climate Appendix.

28. Illinois State Water Survey, Summary of 1966 Hail Research in Illinois, CHIAA Research Report No. 33, Urbana, Illinois.

This report provides data on areal extent of damaging hail in Illinois and analysis of hail records of 225 U. S. Weather Bureau stations in Indiana, Michigan and Illinois.

29. U. S. Weather Bureau, Weather Bureau Survey Team Report of Palm Sunday Tornadoes of 1965, U. S. Department of Commerce, Washington, D. C., (11 April 1965).

30. Michigan Department of Agriculture, Michigan Snowfall Statistics; 1-, 3-, 6-, 12-Inch Depths, Lansing, Michigan, (June 1968)

SECTION IX
METEOROLOGICAL GLOSSARY (27)

1. Air Mass - A large body of air that is approximately homogeneous, with respect to its physical properties, over its horizontal extent.

2. Climate - A summary of all the weather that a specified area has experienced during a specific period of time (usually several decades).

3. Cloud - A visible aggregate of water droplets which remains more or less at a constant altitude above the ground.

4. Cloudiness - A ratio of the amount of cloud cover experienced, to the total amount of sky, expressed in tenths.

5. Continental Climate - Climatic conditions that have not been influenced by large bodies of water. It is marked by large annual, daily, day-to-day ranges of temperature, low relative humidity and generally by a moderate or small and irregular rainfall.

6. Controlled Weather - Alteration of the occurrence or the lack of occurrence of natural phenomena by introduction by man of various artificial means and devices.

7. Convective Storms - A storm that develops from a rapid cooling of relatively warm moist air which rises as a result of surface heating.

8. Cyclone - An atmospheric pressure system characterized by relatively low pressure at its center, and by counterclockwise wind motion in the nothern hemisphere, clockwise in the southern.

9. Dew - The deposit of moisture on exposed surfaces having temperatures below the condensation temperature.

10. Drought - A variable period of time in which water supplies are less than water damands. In meteorological terms, a drought is expressed as a period of time when meteorological phenomena, e.g., precipitation, evaporation, temperature, humidity, wind - are such that water demands are not met.

11. Fog - A visible cloud formation at the earth's surface comprised of water droplets, dust, or smoke particles, or a combination of these.

12. Front - Boundary between 2 air masses of different densities.

13. Hail - A solid form of precipitation that occurs from an oscillating process of raindrops being swept up by strong air currents into regions of freezing temperatures while collecting water droplets until its weight exceeds the uplift forces of the air current, whereupon it descends. As it descends, the hailstone begins to melt until its weight again is exceeded by the uplift forces. The process continues until the weight of the hailstone exceeds the uplift forces at all times in its descent to the earth.

14. Hydrology - The composite study of precipitation including its origin, formation, intensity, duration, distribution, and occurrence.

15. Isohyet - A line depicting equal precipitation.

16. Isotherm - A line depicting equal temperature.

17. Maximum Probable Storm - A storm that could be expected from the most severe combination of meteorological and hydrologic conditions that could exist in a specified area.

18. Meteorology - The study of any component of the earth's atmosphere - temperature, precipitation, solar radiation, wind.

19. Precipitation - Includes all moisture that reaches the earth, whatever its form - rain, snow, sleet, hail, dew, or frost.

20. Relative Humidity - A comparison of the moisture content of the air to the moisture content the air could hold.

21. Semi-marine Climate - Climatic conditions that have been influenced somewhat by large bodies of water.

22. Sleet - A combination of solid and liquid form of precipitation made up of ice and rain.

23. Snow - A crystal form of precipitation that occurs from a freezing of water vapor particles.

24. Solar Radiation - The quantity of energy received at a specific location from the sun.

25. Standard Project Storm - A storm that could be expected from the most severe combination of meteorologic and hydraulic conditions that are considered reasonably characteristic of a specified area.

26. Storm - An atmospheric disturbance characterized by above average winds and the formation of precipitation. It may be accompanied by thunder and lightning.

27. Temperature - A measure of the degree of hotness or coldness above an arbitrary zero on some definite temperature scale.

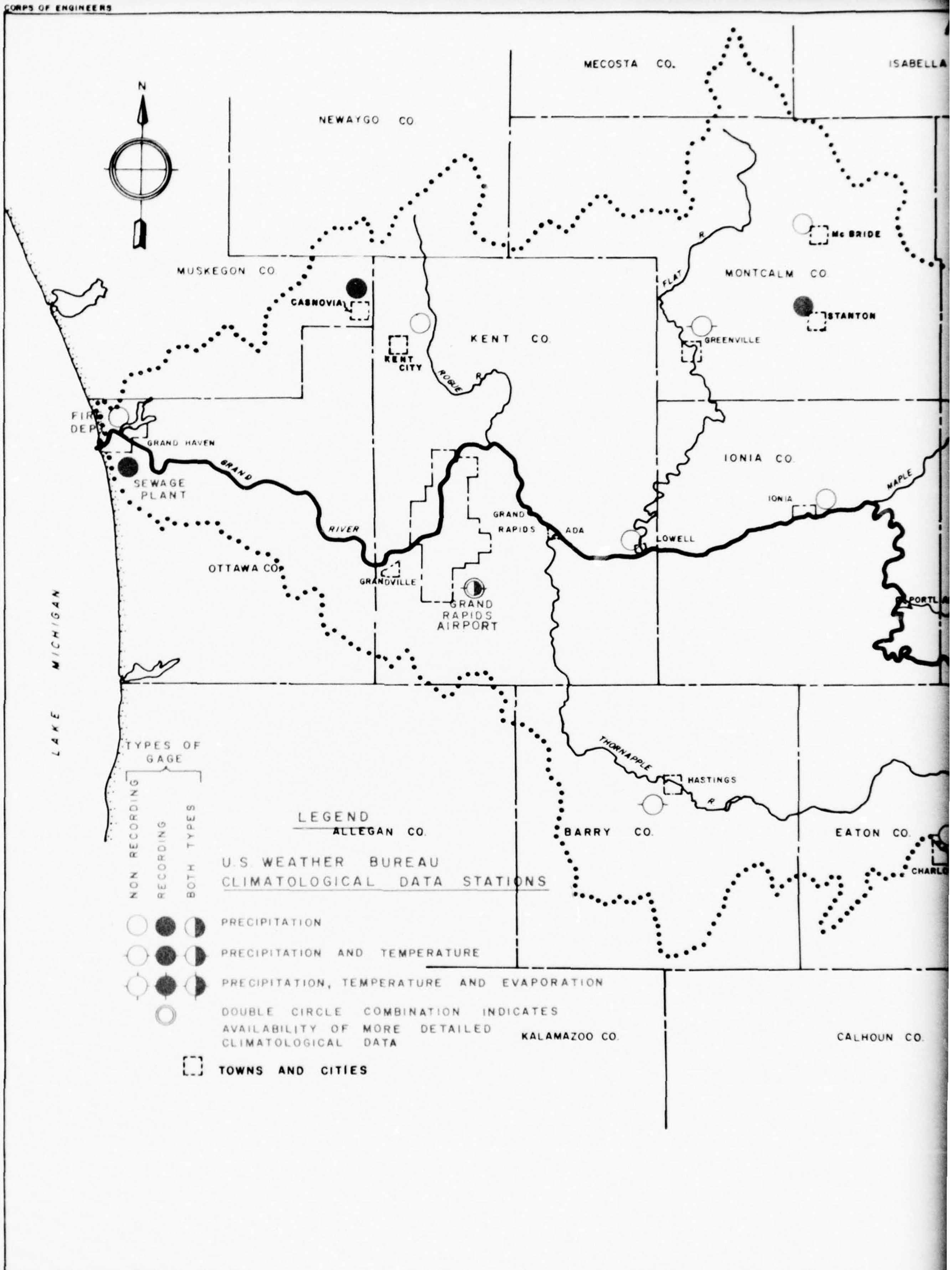
28. Thunderstorm - In the upward air currents associated with convective type storms, large raindrops become broken up and acquire electrical charges, which accumulate until the potential becomes sufficient to cause a lightning charge to occur to either earth or another cloud. The thunder noise has its origin in the violent temperature changes accompanying the lightning.

29. Tornado - A destructive rotating column of air that originates from rapidly ascending air currents.

30. Weather Forecast - A summary of meteorological conditions that can be expected, within designated periods of time, based on existing meteorological conditions.

31. Frost - frozen dew.

32. Rain - Water falling in drops condensed from vapor in the atmosphere.



CORPS OF ENGINEERS
N
MECOSTA CO.
ISABELLA
NEWAYGO CO.
MUSKEGON CO.
CASNOVIA
MONTCALM CO.
Mc BRIDE
STANTON
GREENVILLE
FLAT
R
KENT CO.
KENT CITY
ROGUE R
GRAND HAVEN
SEWAGE PLANT
GRAND
RIVER
IONIA CO.
IONIA
MAPLE
GRAND RAPIDS
ADA
LOWELL
OTTAWA CO.
GRANDVILLE
GRAND RAPIDS AIRPORT
LAKE MICHIGAN
THORNAPPLE
R
HASTINGS
TYPES OF GAGE
NON RECORDING
RECORDING
BOTH TYPES
LEGEND
ALLEGAN CO.
BARRY CO.
EATON CO.
U.S. WEATHER BUREAU
CLIMATOLOGICAL DATA STATIONS
PRECIPITATION
PRECIPITATION AND TEMPERATURE
PRECIPITATION, TEMPERATURE AND EVAPORATION
DOUBLE CIRCLE COMBINATION INDICATES AVAILABILITY OF MORE DETAILED CLIMATOLOGICAL DATA
KALAMAZOO CO.
CALHOUN CO.
TOWNS AND CITIES

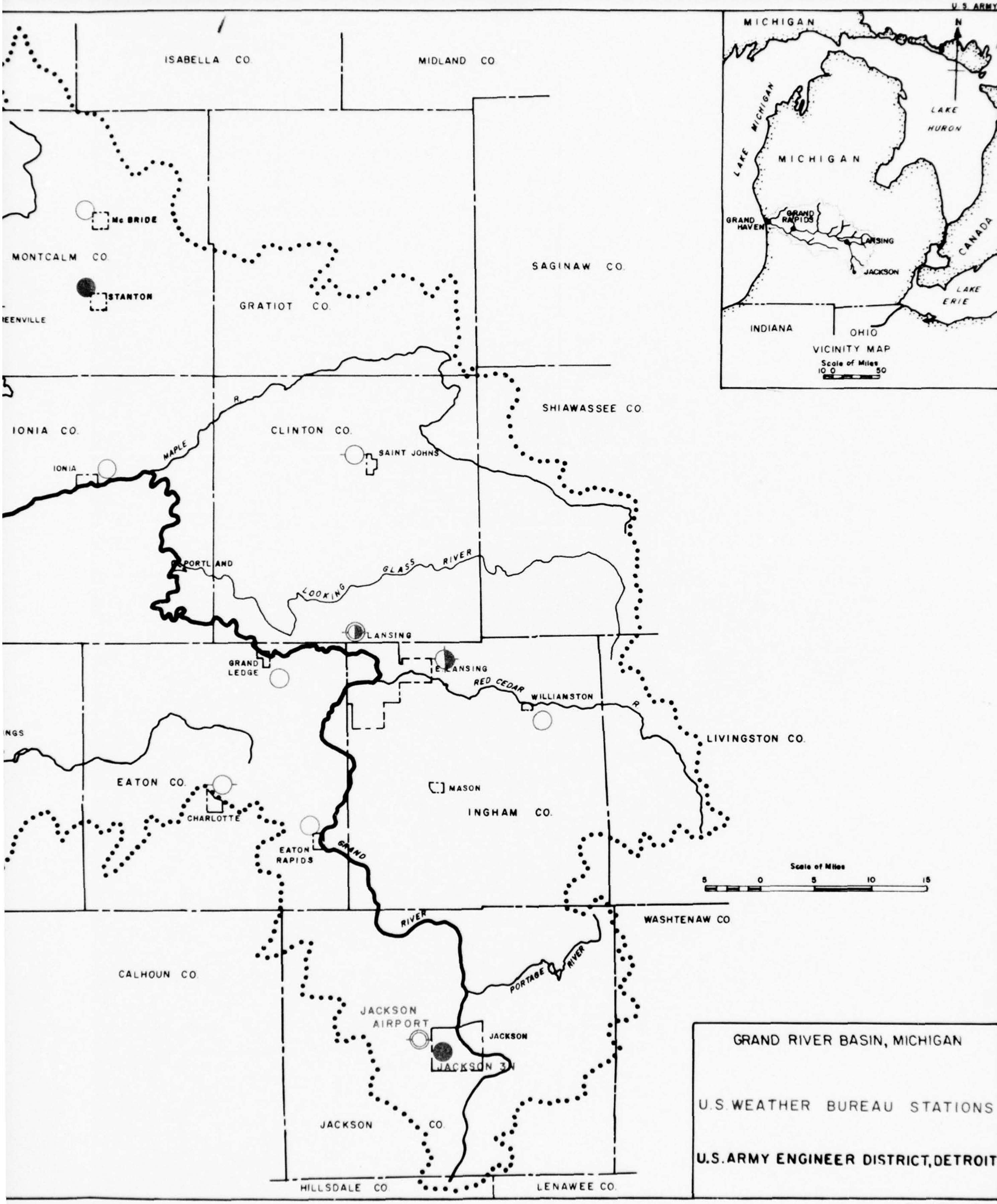
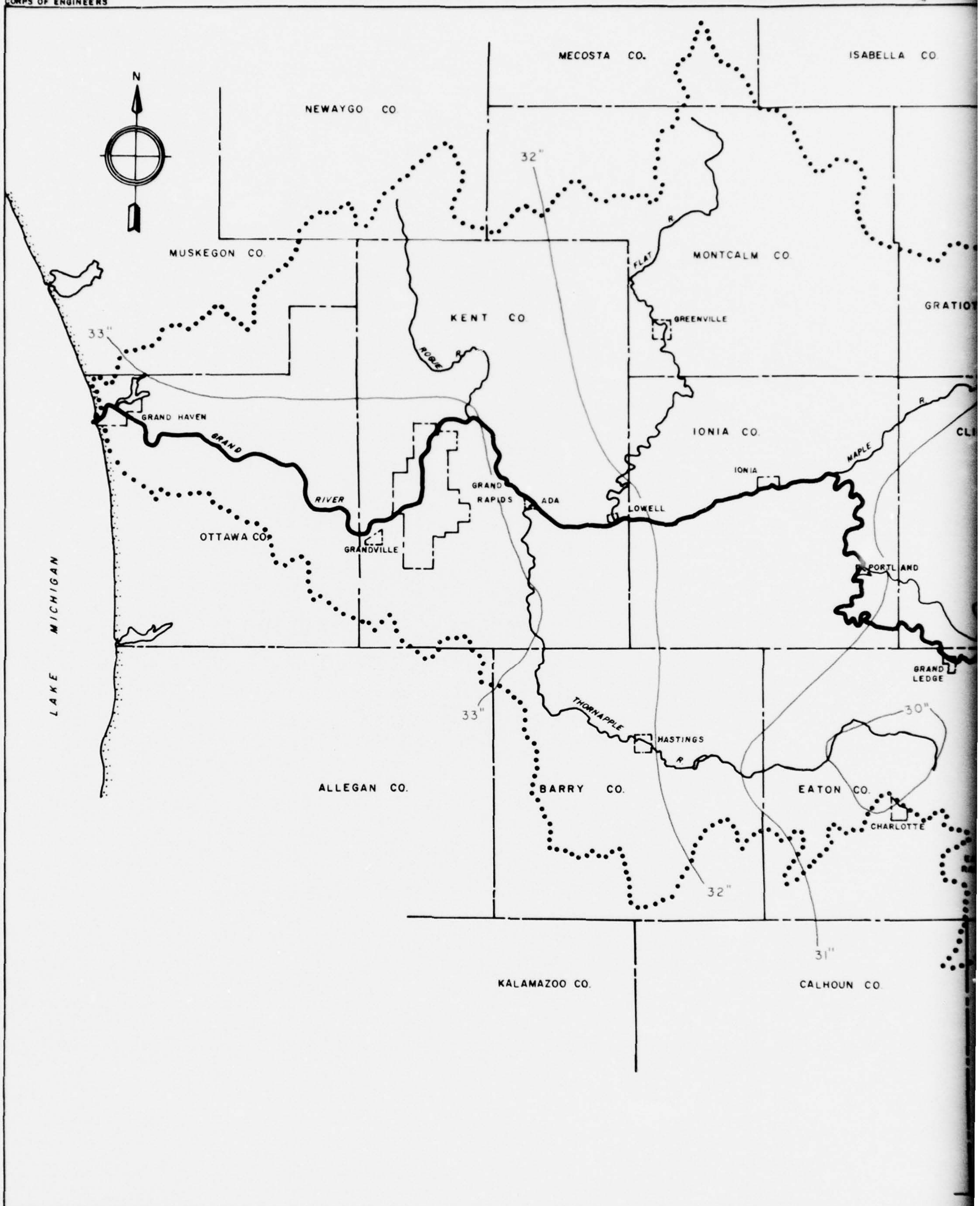
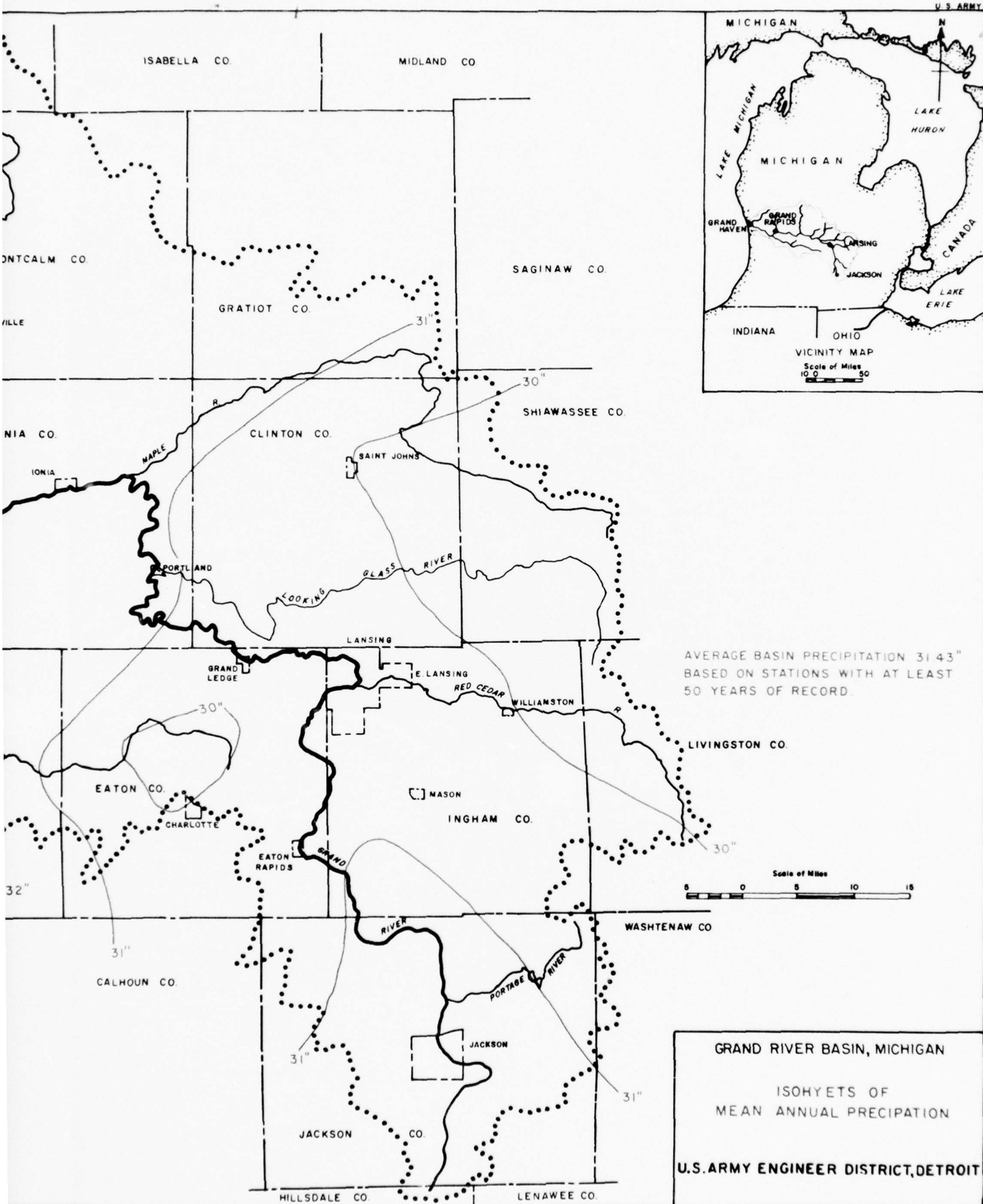

U.S. ARMY
MICHIGAN
LAKE MICHIGAN
LAKE HURON
MICHIGAN
GRAND HAVEN
GRAND RAPIDS
LANSING
JACKSON
CANADA
LAKE ERIE
INDIANA
OHIO
VICINITY MAP
Scale of Miles
10 0 50
ISABELLA CO.
MIDLAND CO.
Mc BRIDE
MONTCALM CO.
STANTON
GREENVILLE
GRATIOT CO.
SAGINAW CO.
SHIAWASSEE CO.
IONIA CO.
CLINTON CO.
MAPLE R.
IONIA
SAINT JOHNS
PORTLAND
LOOKING GLASS RIVER
LANSING
E. LANSING
GRAND LEDGE
RED CEDAR R.
WILLIAMSTON
LIVINGSTON CO.
EATON CO.
CHARLOTTE
MASON
INGHAM CO.
EATON RAPIDS
GRAND RIVER
Scale of Miles
5 0 5 10 15
WASHTENAW CO.
CALHOUN CO.
PORTAGE RIVER
JACKSON AIRPORT
JACKSON
JACKSON 3N
JACKSON CO.
HILLSDALE CO.
LENAWEE CO.
GRAND RIVER BASIN, MICHIGAN
U.S. WEATHER BUREAU STATIONS
U.S. ARMY ENGINEER DISTRICT, DETROIT

PLATE C-1


N
MECOSTA CO.
ISABELLA CO.
NEWAYGO CO.
32"
MUSKEGON CO.
MONTCALM CO.
FLAT R.
GREENVILLE
KENT CO.
GRATIOT
33"
ROGUE R.
GRAND HAVEN
GRAND
IONIA CO.
MAPLE R.
CLI
IONIA
GRAND RAPIDS
ADA
LOWELL
RIVER
OTTAWA CO.
GRANDVILLE
PORTLAND
LAKE MICHIGAN
GRAND LEDGE
33"
THORNAPPLE R.
HASTINGS
30"
ALLEGAN CO.
BARRY CO.
EATON CO.
CHARLOTTE
32"
31"
KALAMAZOO CO.
CALHOUN CO.

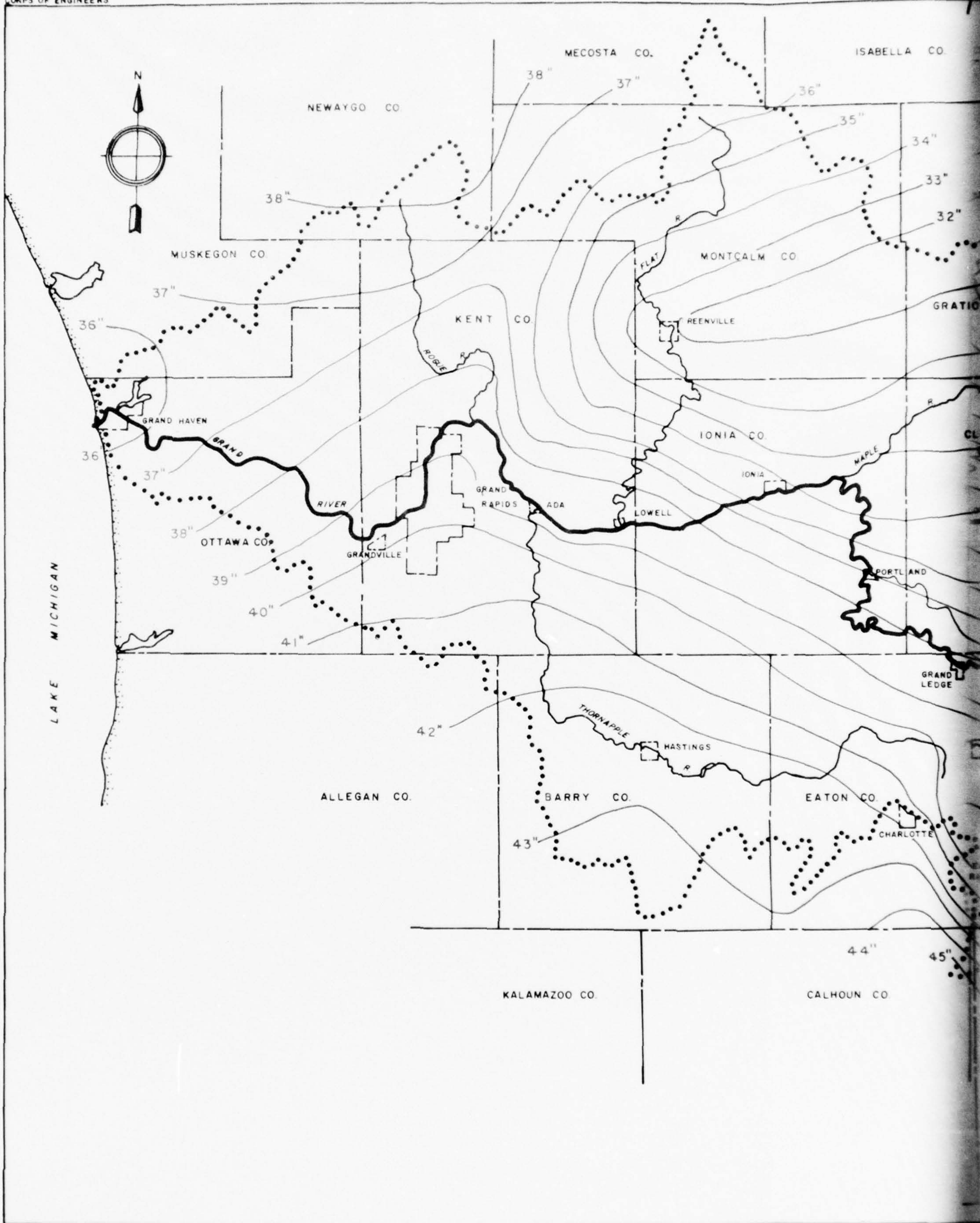


GRAND RIVER BASIN, MICHIGAN

ISOHYETS OF
MEAN ANNUAL PRECIPATION

U.S. ARMY ENGINEER DISTRICT, DETROIT

PLATE C-2


N
MECOSTA CO.
ISABELLA CO.
NEWAYGO CO.
MUSKEGON CO.
MONTCALM CO.
KENT CO.
GREENVILLE
GRAND HAVEN
GRAND RIVER
IONIA CO.
IONIA
MAPLE R
ROGUE R
FLAT R
GRAND RAPIDS
ADA
LOWELL
OTTAWA CO.
GRANDVILLE
PORTLAND
GRAND LEDGE
LAKE MICHIGAN
THORNAPPLE R
HASTINGS
ALLEGAN CO.
BARRY CO.
EATON CO.
CHARLOTTE
KALAMAZOO CO.
CALHOUN CO.
32"
33"
34"
35"
36"
37"
38"
39"
40"
41"
42"
43"
44"
45"

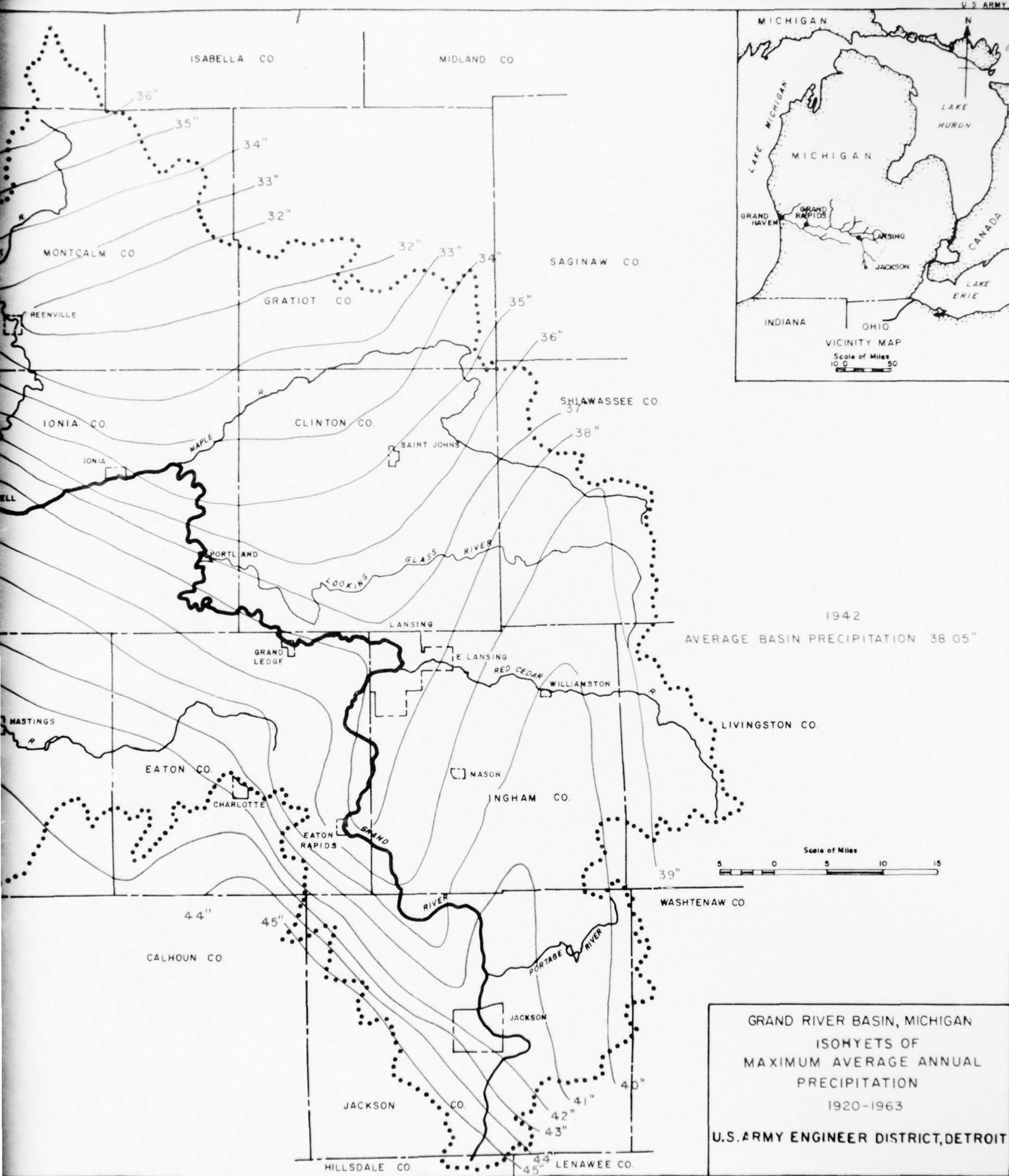
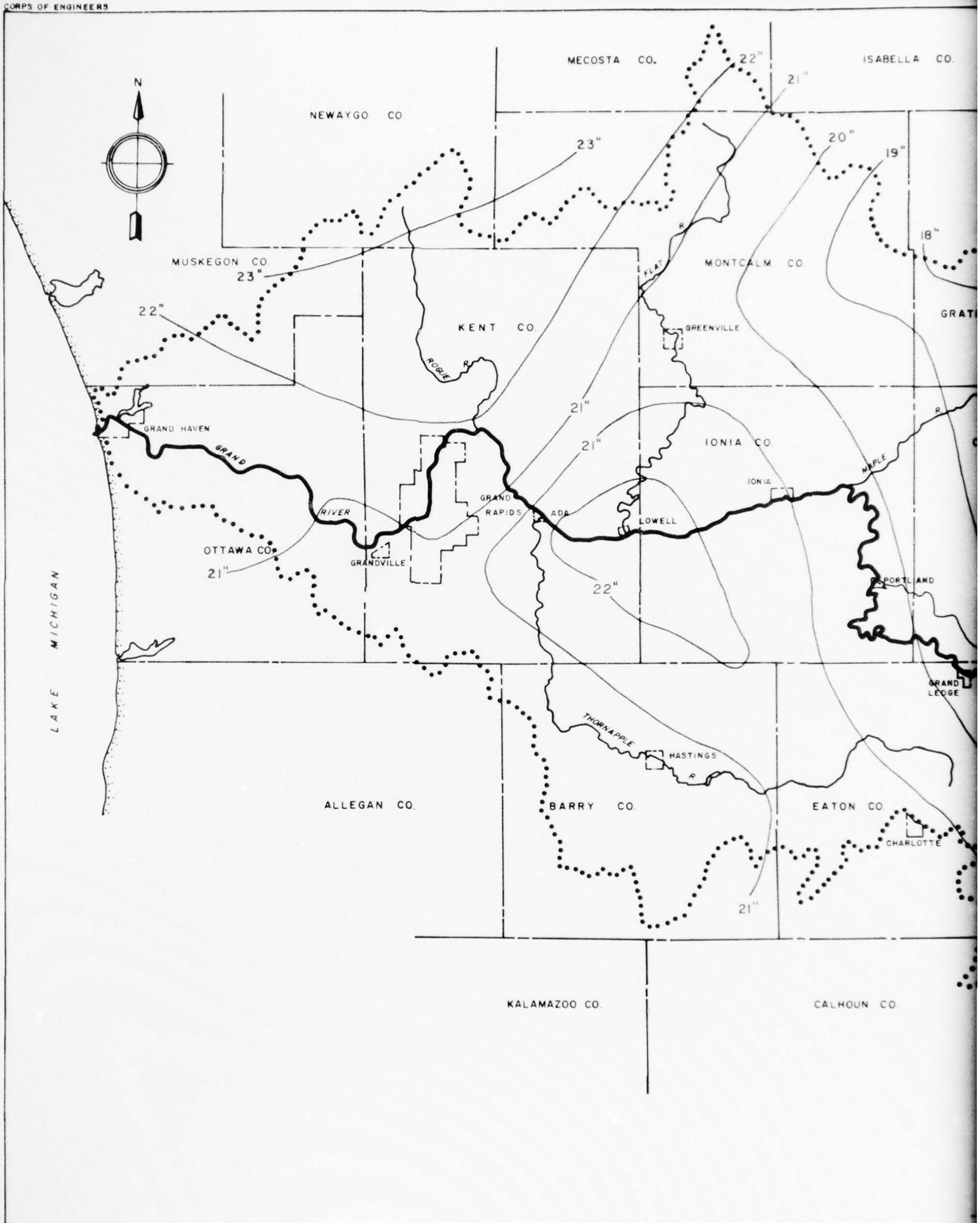

U.S. ARMY
MICHIGAN
LAKE MICHIGAN
LAKE HURON
MICHIGAN
GRAND HAVEN
GRAND RAPIDS
LANSING
JACKSON
CANADA
LAKE ERIE
INDIANA
OHIO
VICINITY MAP
Scale of Miles
ISABELLA CO.
MIDLAND CO.
MONTCALM CO.
GRATIOT CO.
SAGINAW CO.
GREENVILLE
IONIA CO.
CLINTON CO.
SHIAWASSEE CO.
IONIA
SAINT JOHNS
MAPLE R.
PORTLAND
LOOKING GLASS RIVER
LANSING
GRAND LEDGE
E. LANSING
RED CEDAR R.
WILLIAMSTON
HASTINGS
LIVINGSTON CO.
EATON CO.
CHARLOTTE
MASON
INGHAM CO.
EATON RAPIDS
GRAND RIVER
WASHTENAW CO.
PORTAGE RIVER
CALHOUN CO.
JACKSON
JACKSON CO.
HILLSDALE CO.
LENAWEE CO.
Scale of Miles
5 0 5 10 15
32" 33" 34" 35" 36" 37" 38" 39" 40" 41" 42" 43" 44" 45"
1942
AVERAGE BASIN PRECIPITATION 38.05"
GRAND RIVER BASIN, MICHIGAN
ISOHYETS OF
MAXIMUM AVERAGE ANNUAL
PRECIPITATION
1920-1963
U.S. ARMY ENGINEER DISTRICT, DETROIT

PLATE C-3

CORPS OF ENGINEERS



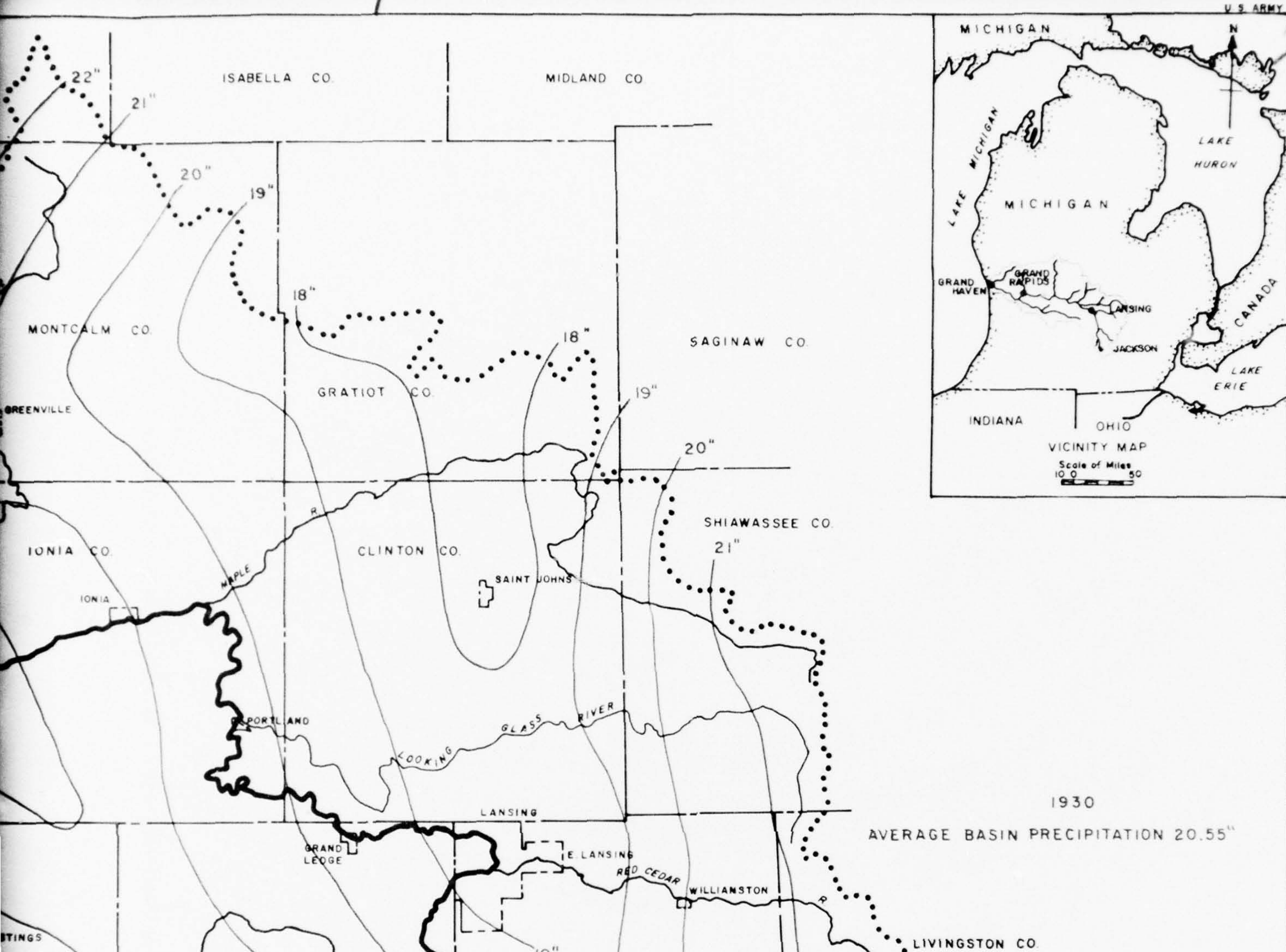
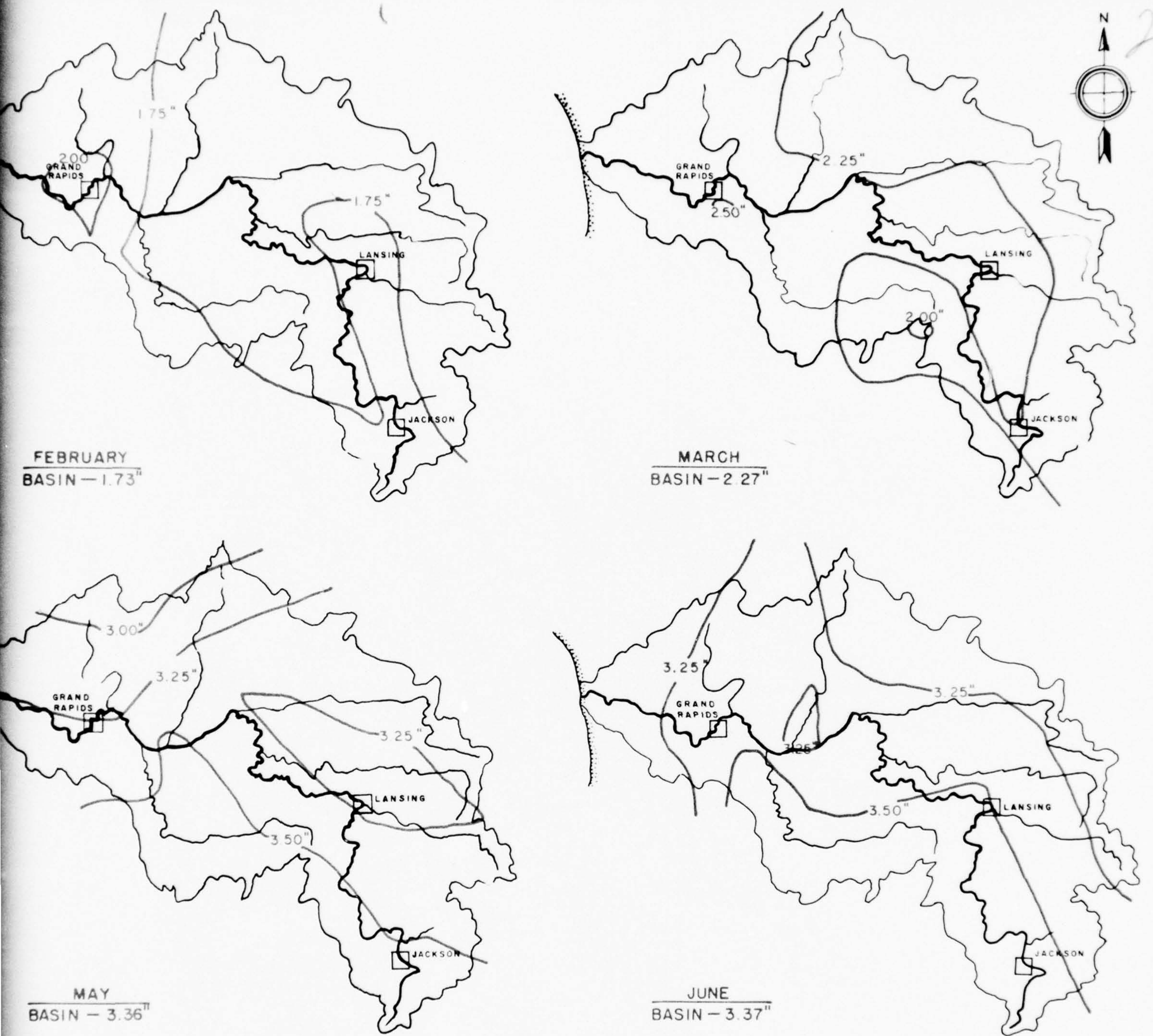

U.S. ARMY
ISABELLA CO.
MIDLAND CO.
MONTCALM CO.
GREENVILLE
GRATIOT CO.
SAGINAW CO.
IONIA CO.
IONIA
CLINTON CO.
SAINT JOHNS
SHIAWASSEE CO.
MAPLE R.
LOOKING GLASS RIVER
PORTLAND
LANSING
E. LANSING
GRAND LEDGE
RED CEDAR
WILLIANSTON
LIVINGSTON CO.
EATON CO.
CHARLOTTE
MASON
INGHAM CO.
EATON RAPIDS
GRAND RIVER
CALHOUN CO.
WASHTENAW CO.
PORTAGE RIVER
JACKSON
JACKSON CO.
HILLSDALE CO.
LENAWEE CO.
22"
21"
20"
19"
18"
1930
AVERAGE BASIN PRECIPITATION 20.55"
Scale of Miles
5 0 5 10 15
MICHIGAN
LAKE MICHIGAN
LAKE HURON
GRAND HAVEN
GRAND RAPIDS
LANSING
JACKSON
CANADA
LAKE ERIE
INDIANA
OHIO
VICINITY MAP
Scale of Miles
10 0 50
GRAND RIVER BASIN, MICHIGAN
ISOHYETS OF MINIMUM
AVERAGE ANNUAL PRECIPITATION
1920-1963
U.S. ARMY ENGINEER DISTRICT, DETROIT

PLATE C-4


2.00"
GRAND RAPIDS
1.75"
LANSING
JACKSON
JANUARY
BASIN — 1.87"
1.75"
2.00
GRAND RAPIDS
FEBRUARY
BASIN — 1.73"
4.00"
3.75"
3.50"
3.25"
3.00"
2.75"
GRAND RAPIDS
LANSING
2.75"
3.00"
JACKSON
APRIL
BASIN — 2.88"
3.00"
3.25"
GRAND RAPIDS
3.50"
MAY
BASIN — 3.36"
SCALE OF MILES
10 0 10 20 30 40 50



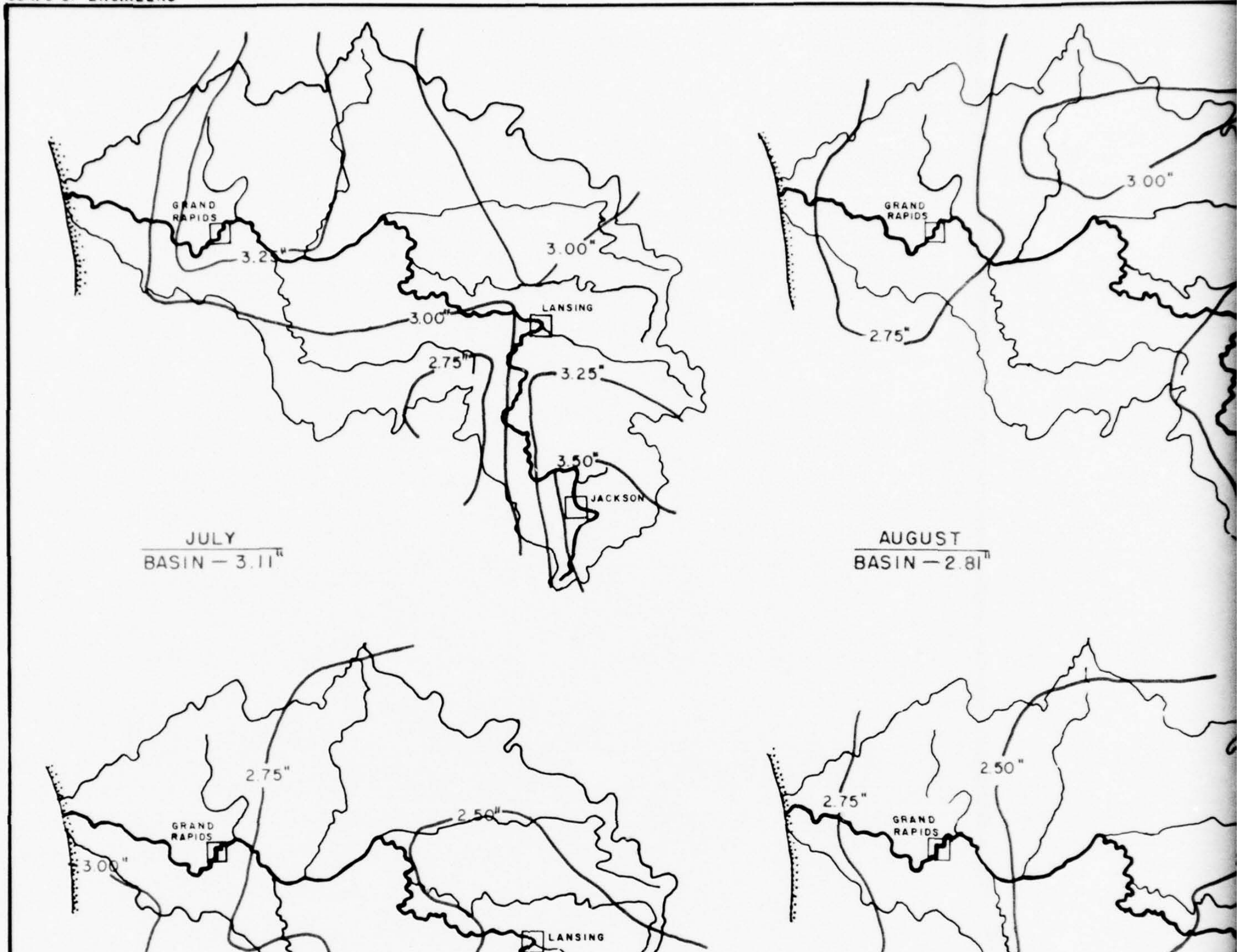
NOTE:
BASIN AVERAGE BASED ON STATIONS WITH AT LEAST 50 YEARS OF RECORD.

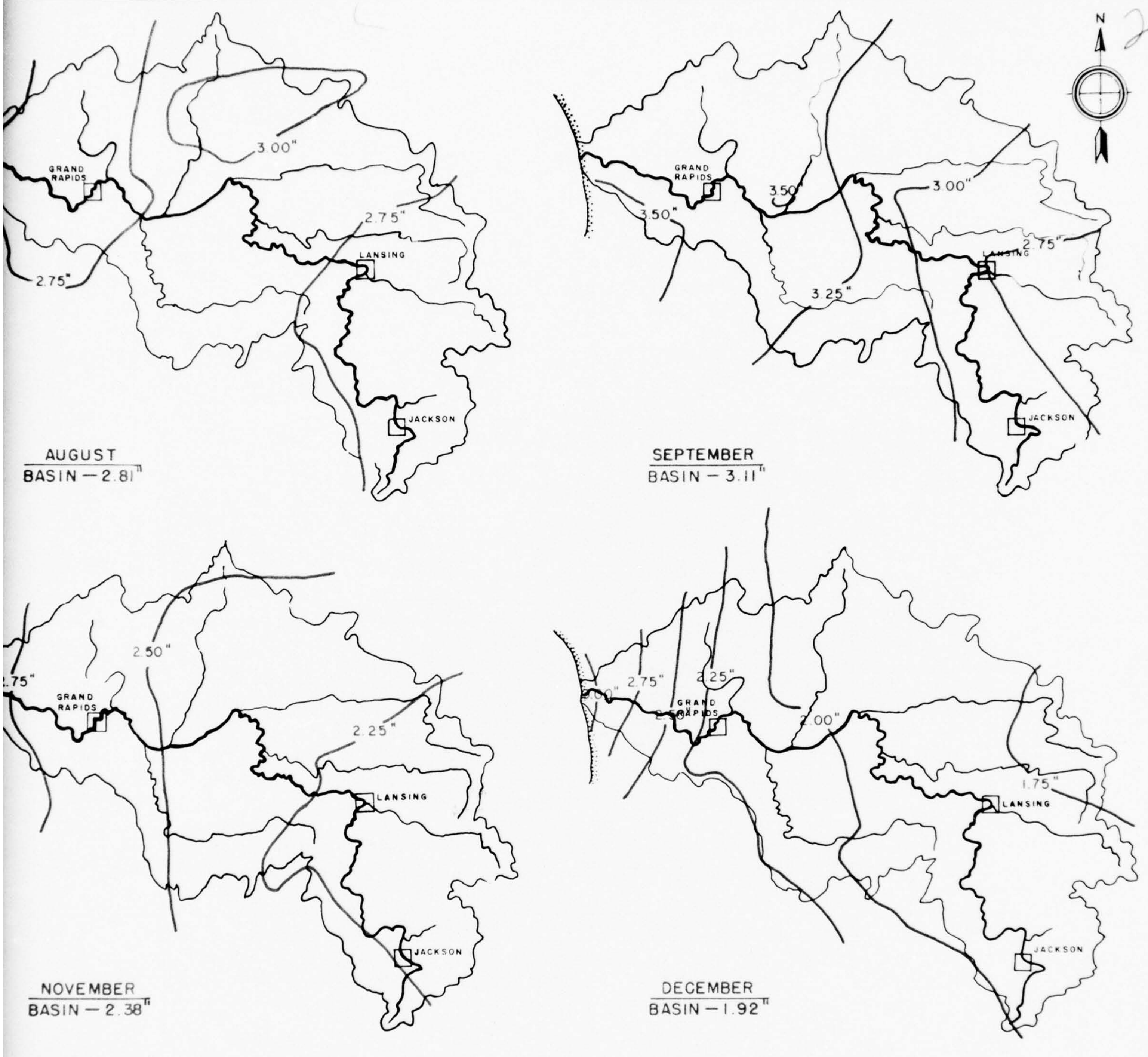
CALE OF MILES
20 30 40 50

GRAND RIVER BASIN, MICHIGAN
ISOHYETS OF MEAN
MONTHLY AVERAGE PRECIPITATION
JANUARY — JUNE

U.S. ARMY ENGINEER DISTRICT, DETROIT

CORPS OF ENGINEERS





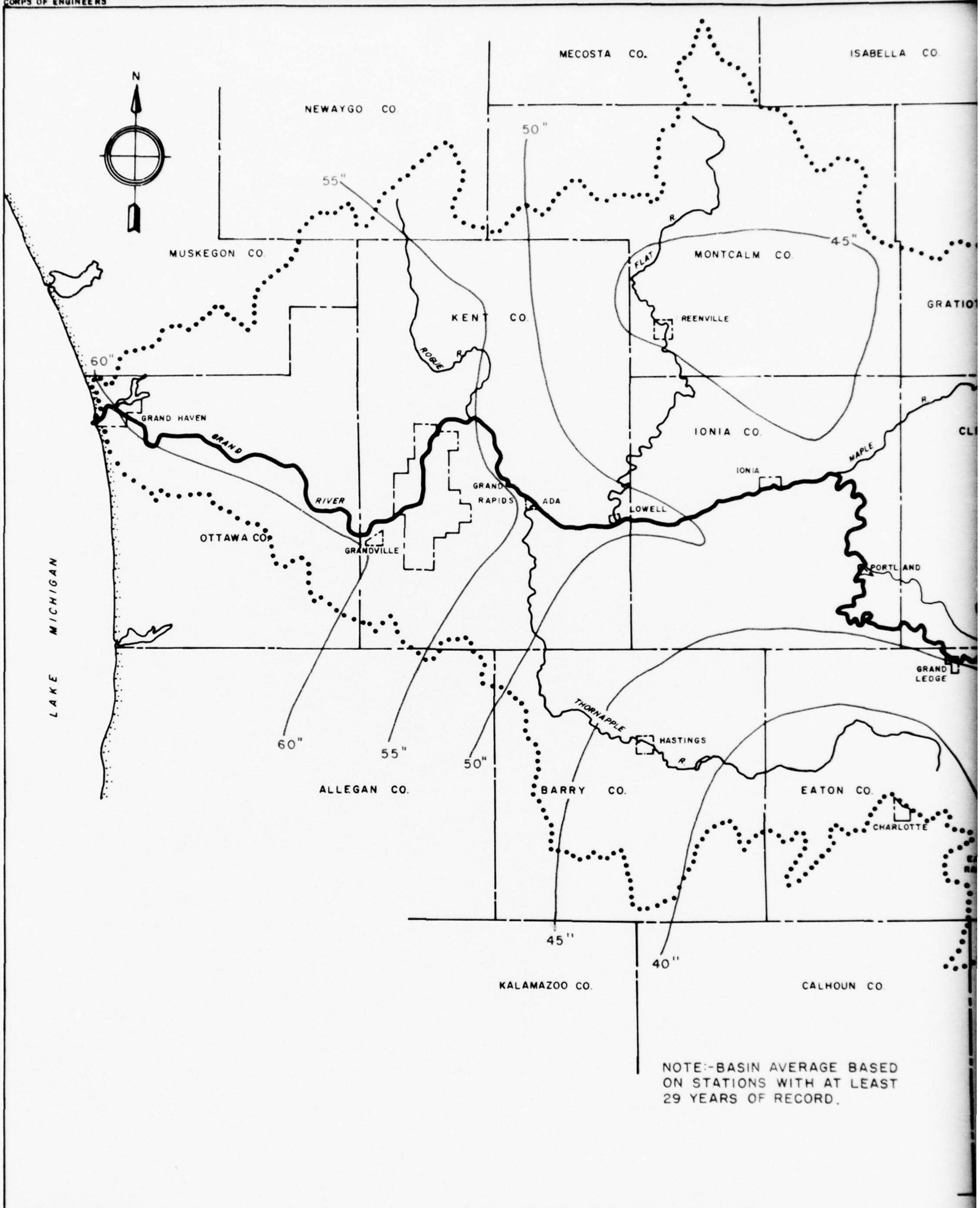
NOTE:
BASIN AVERAGE BASED ON STATIONS WITH AT LEAST 50 YEARS OF RECORD.

SCALE OF MILES
10 20 30 40 50

GRAND RIVER BASIN, MICHIGAN

ISOHYETS OF MEAN MONTHLY AVERAGE PRECIPITATION
JULY — DECEMBER

U.S. ARMY ENGINEER DISTRICT, DETROIT



NOTE:-BASIN AVERAGE BASED ON STATIONS WITH AT LEAST 29 YEARS OF RECORD.

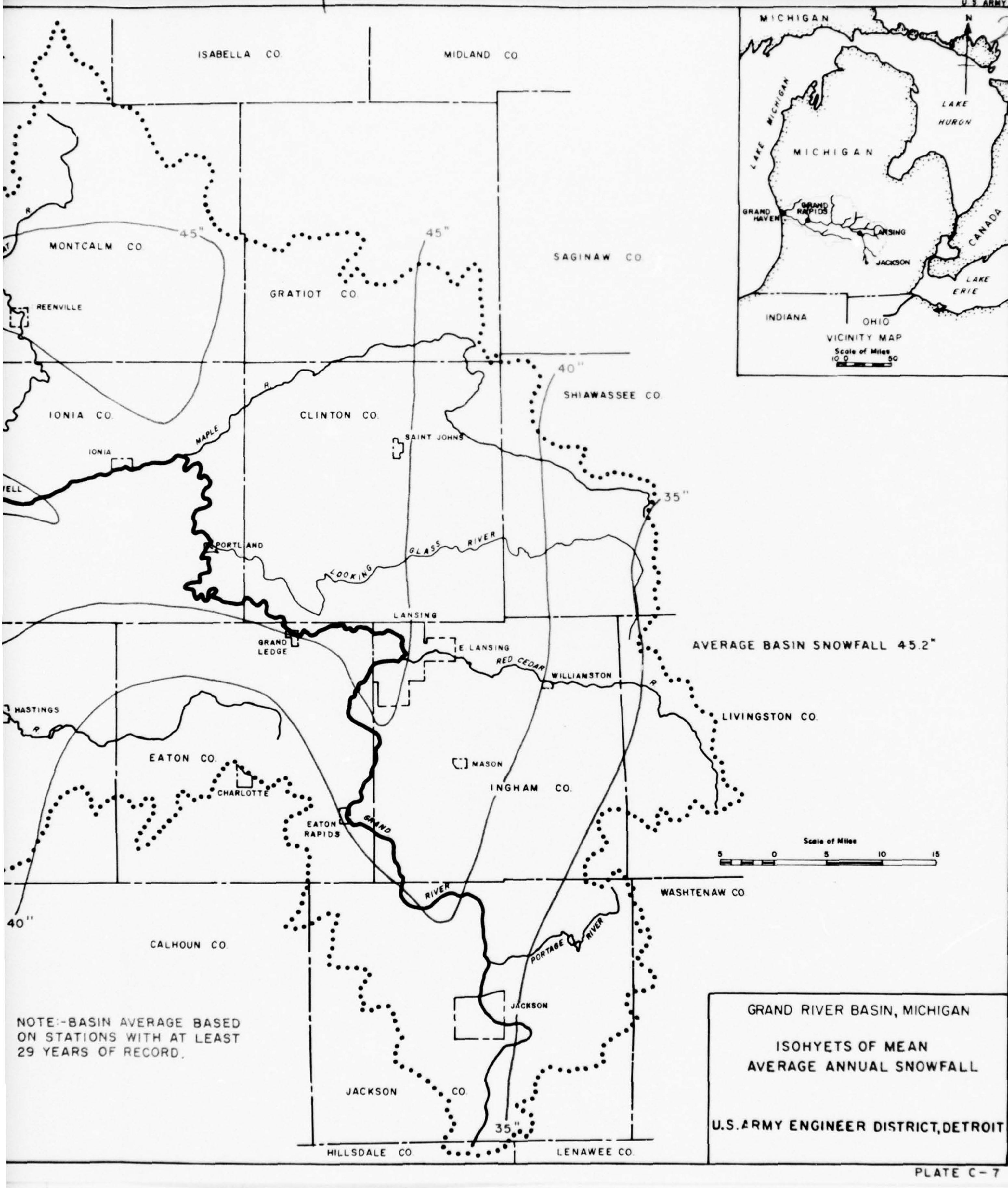
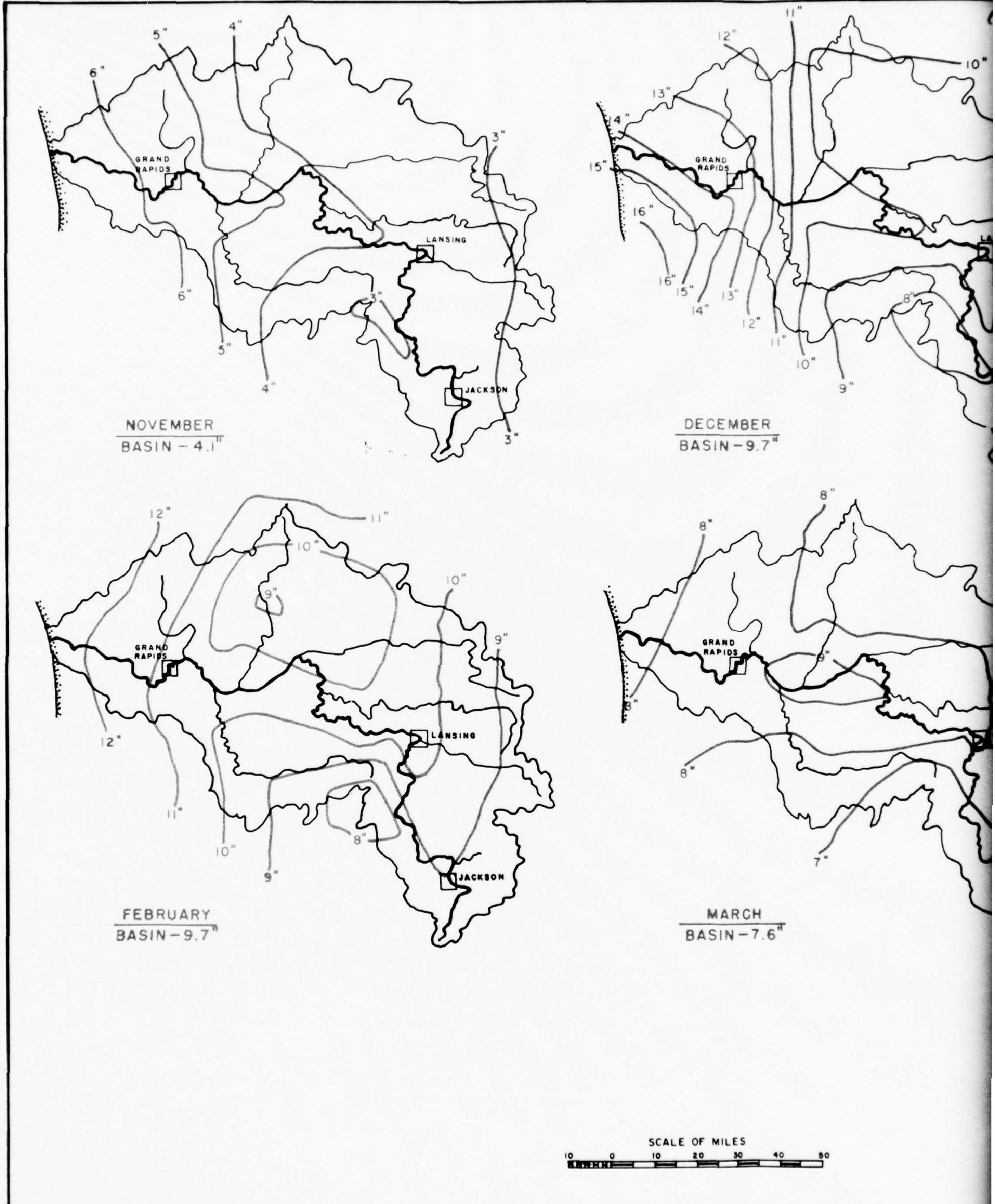
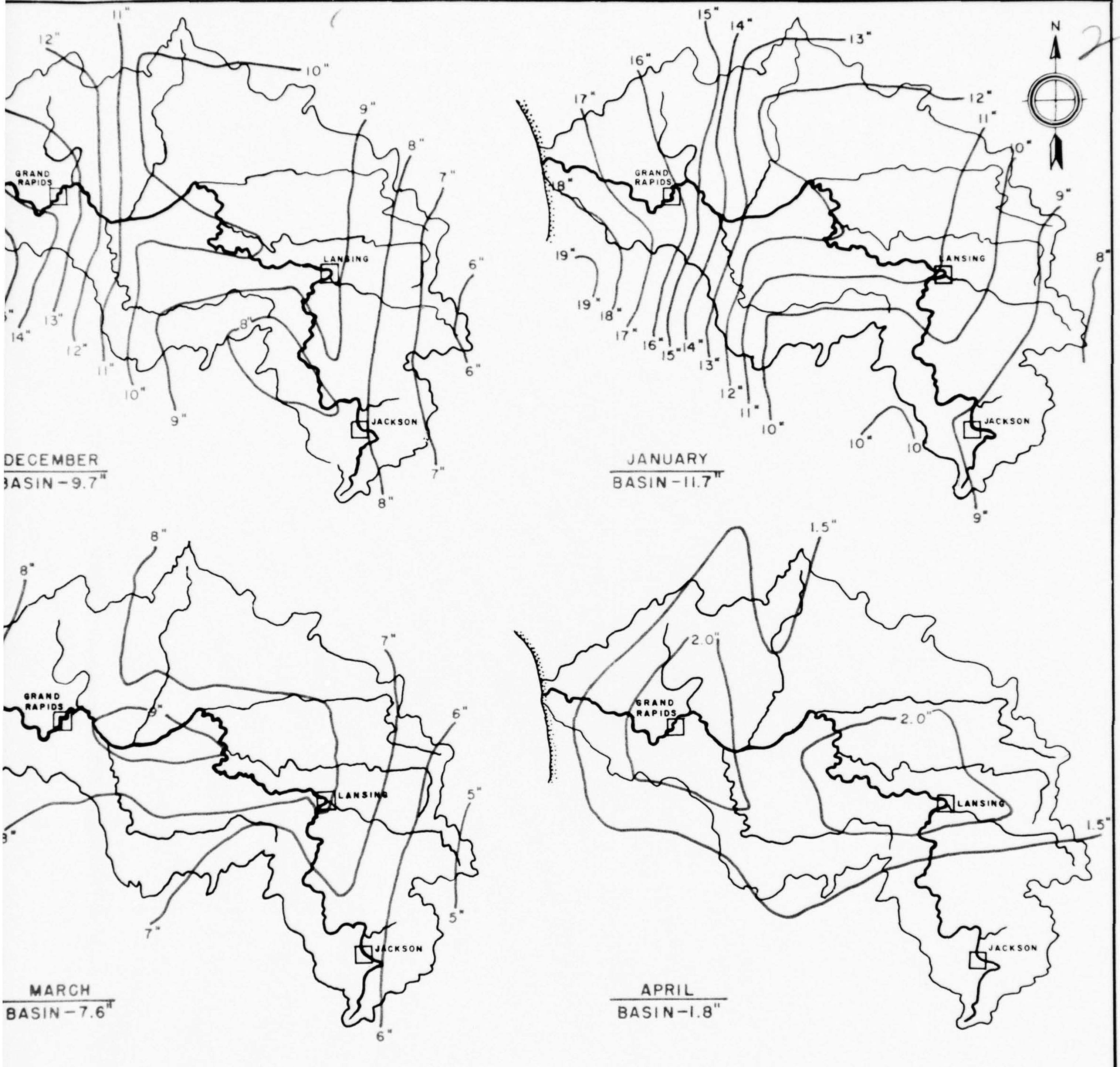

U S ARMY
MICHIGAN
LAKE MICHIGAN
LAKE HURON
MICHIGAN
GRAND HAVEN
GRAND RAPIDS
LANSING
JACKSON
CANADA
LAKE ERIE
INDIANA
OHIO
VICINITY MAP
Scale of Miles
ISABELLA CO.
MIDLAND CO.
MONTCALM CO.
GRATIOT CO.
SAGINAW CO.
45"
40"
35"
REENVILLE
IONIA CO.
CLINTON CO.
SHIAWASSEE CO.
MAPLE R.
IONIA
SAINT JOHNS
PORTLAND
LOOKING GLASS RIVER
LANSING
GRAND LEDGE
E. LANSING
RED CEDAR
WILLIAMSTON
AVERAGE BASIN SNOWFALL 45.2"
HASTINGS
LIVINGSTON CO.
EATON CO.
CHARLOTTE
MASON
INGHAM CO.
EATON RAPIDS
GRAND RIVER
Scale of Miles
5 0 5 10 15
WASHTENAW CO.
CALHOUN CO.
PORTAGE RIVER
JACKSON
NOTE:-BASIN AVERAGE BASED ON STATIONS WITH AT LEAST 29 YEARS OF RECORD.
JACKSON CO.
HILLSDALE CO.
LENAWEE CO.
GRAND RIVER BASIN, MICHIGAN
ISOHYETS OF MEAN AVERAGE ANNUAL SNOWFALL
U.S. ARMY ENGINEER DISTRICT, DETROIT

PLATE C-7

CORPS OF ENGINEERS





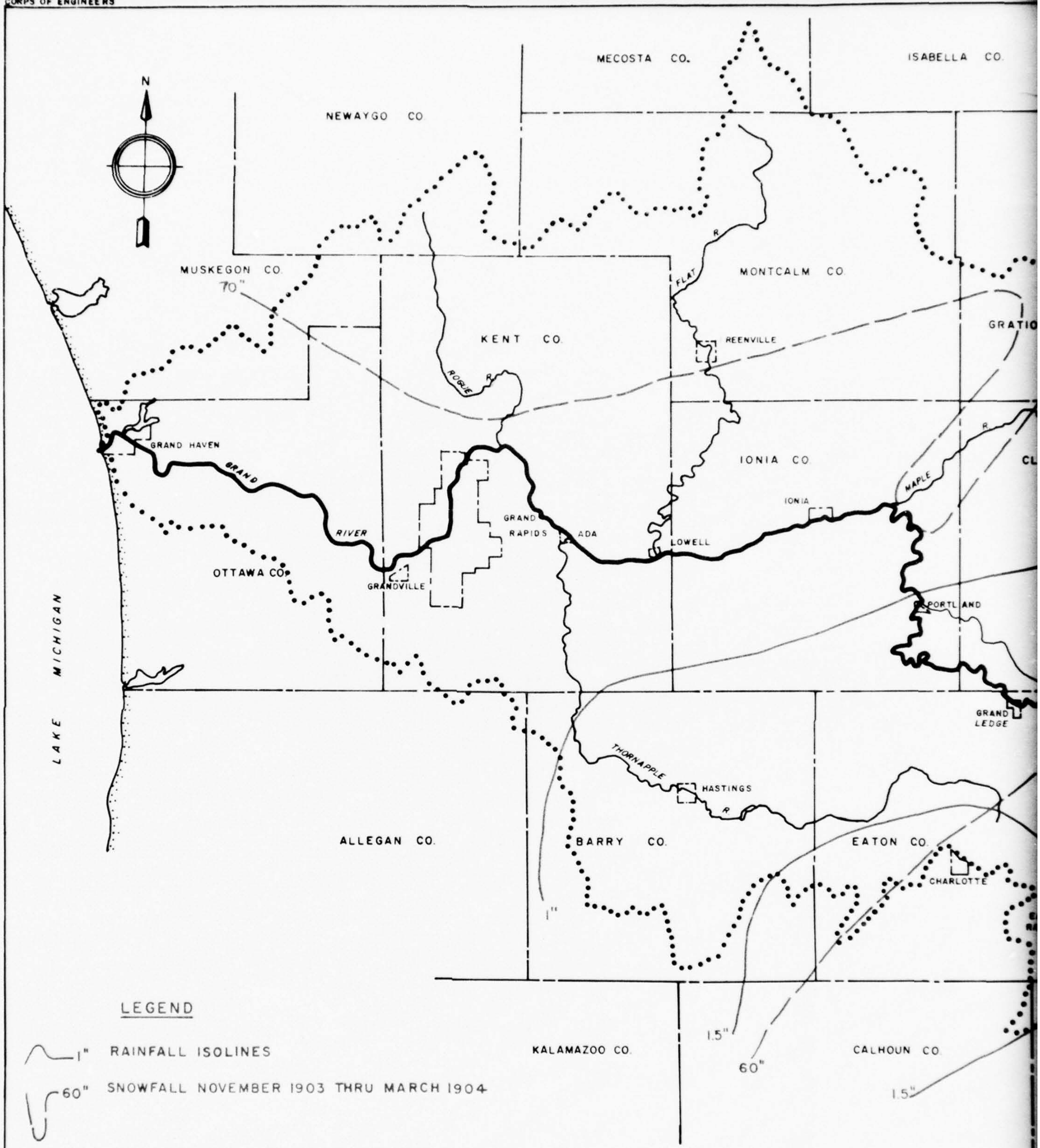
NOTE:
BASIN AVERAGE BASED ON
STATIONS WITH AT LEAST
29 YEARS OF RECORD.

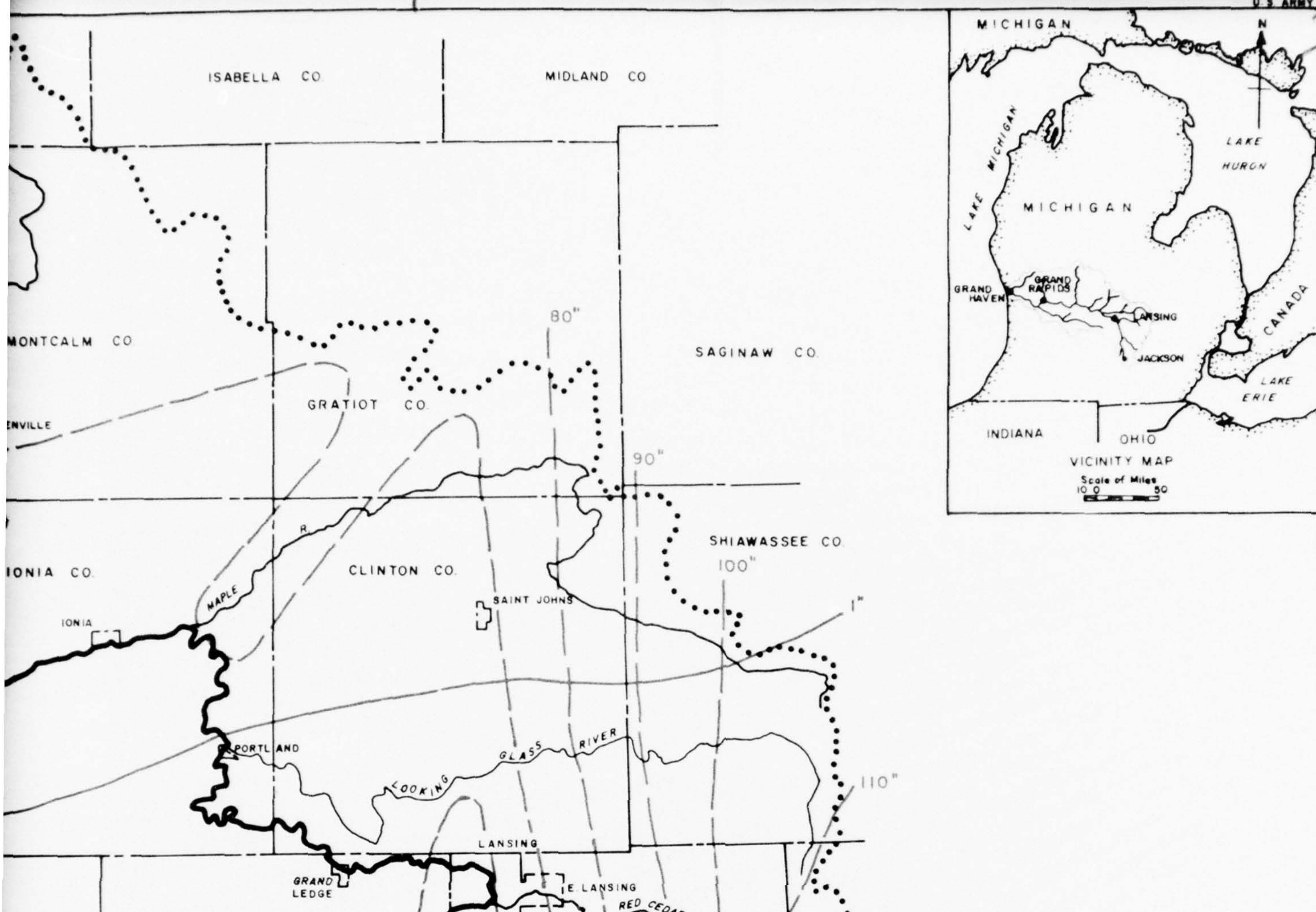
E OF MILES
20 30 40 50

GRAND RIVER BASIN, MICHIGAN

ISOHYETS OF
MEAN MONTHLY SNOWFALL
NOVEMBER-APRIL

U.S. ARMY ENGINEER DISTRICT, DETROIT


MECOSTA CO.
ISABELLA CO.
NEWAYGO CO.
N
MUSKEGON CO.
70"
MONTCALM CO.
FLAT
R
KENT CO.
ROGUE
R
REENVILLE
GRATIO
GRAND HAVEN
GRAND
RIVER
IONIA CO.
MAPLE
R
CL
IONIA
GRAND
RAPIDS
ADA
LOWELL
OTTAWA CO.
GRANDVILLE
PORTLAND
LAKE MICHIGAN
GRAND
LEDGE
THORNAPPLE
R
HASTINGS
ALLEGAN CO.
BARRY CO.
EATON CO.
CHARLOTTE
1"
LEGEND
1" RAINFALL ISOLINES
60" SNOWFALL NOVEMBER 1903 THRU MARCH 1904
KALAMAZOO CO.
1.5"
60"
CALHOUN CO.
1.5"

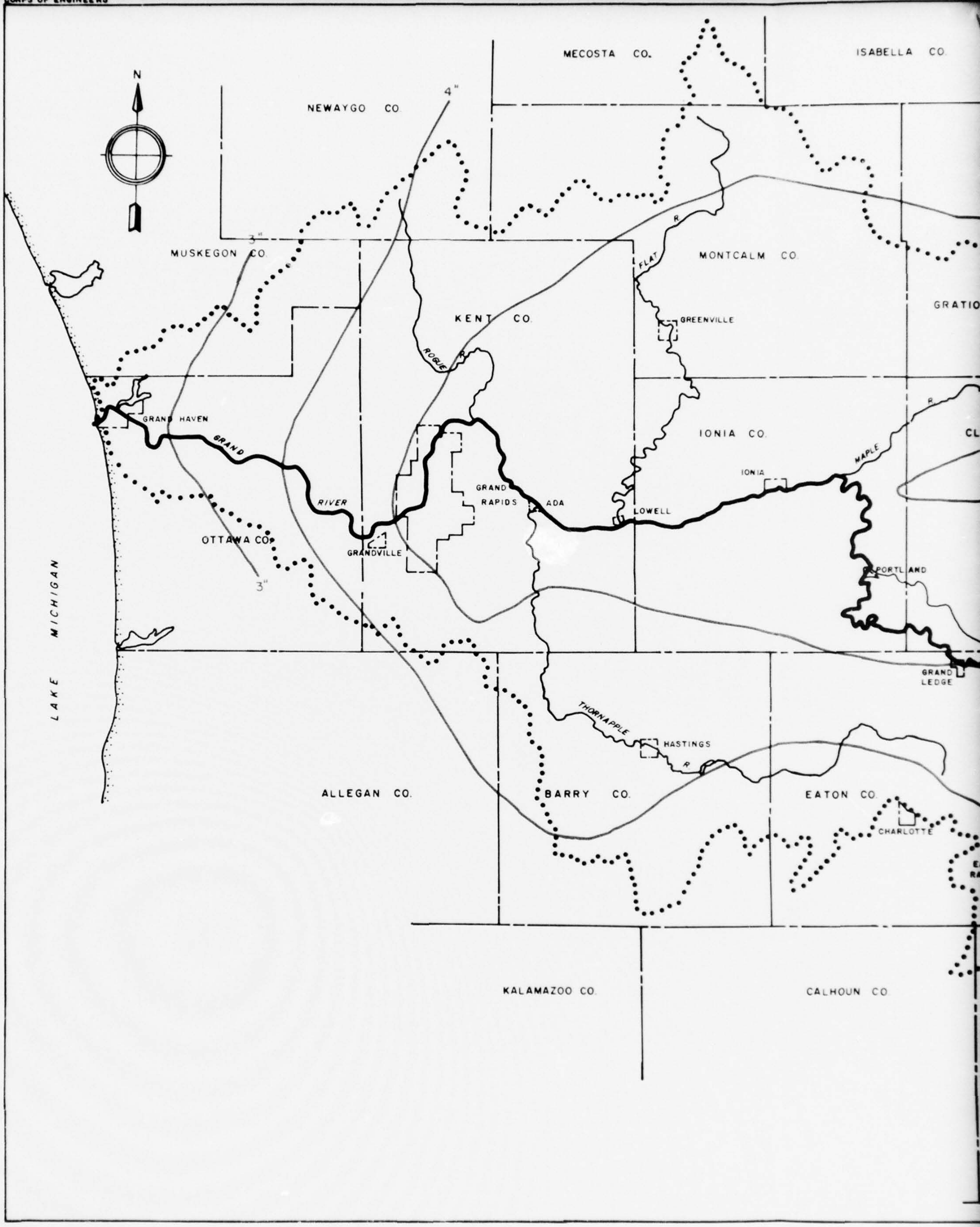


GRAND RIVER BASIN, MICHIGAN

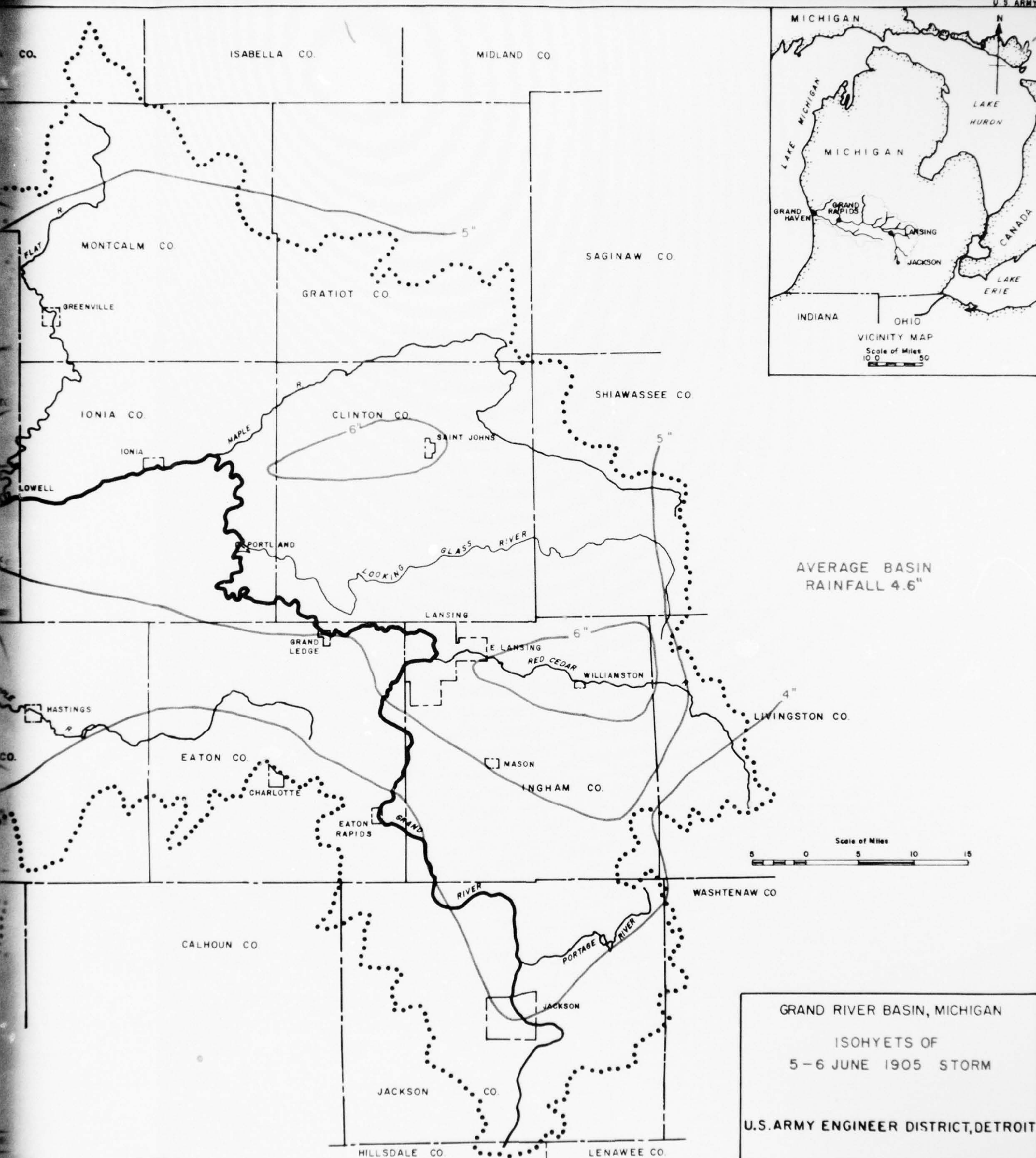
ISOHYETS OF
24-27 MARCH 1904 STORM

U.S. ARMY ENGINEER DISTRICT, DETROIT

PLATE C-9



N
MECOSTA CO.
ISABELLA CO.
NEWAYGO CO.
4"
3"
MUSKEGON CO.
MONTCALM CO.
FLAT R
GRATIOT
KENT CO.
GREENVILLE
ROGUE R
GRAND HAVEN
GRAND
RIVER
IONIA CO.
R
MAPLE
IONIA
GRAND RAPIDS
ADA
LOWELL
OTTAWA CO.
GRANDVILLE
3"
PORTLAND
LAKE MICHIGAN
GRAND LEDGE
THORNAPPLE
HASTINGS
R
ALLEGAN CO.
BARRY CO.
EATON CO.
CHARLOTTE
KALAMAZOO CO.
CALHOUN CO.

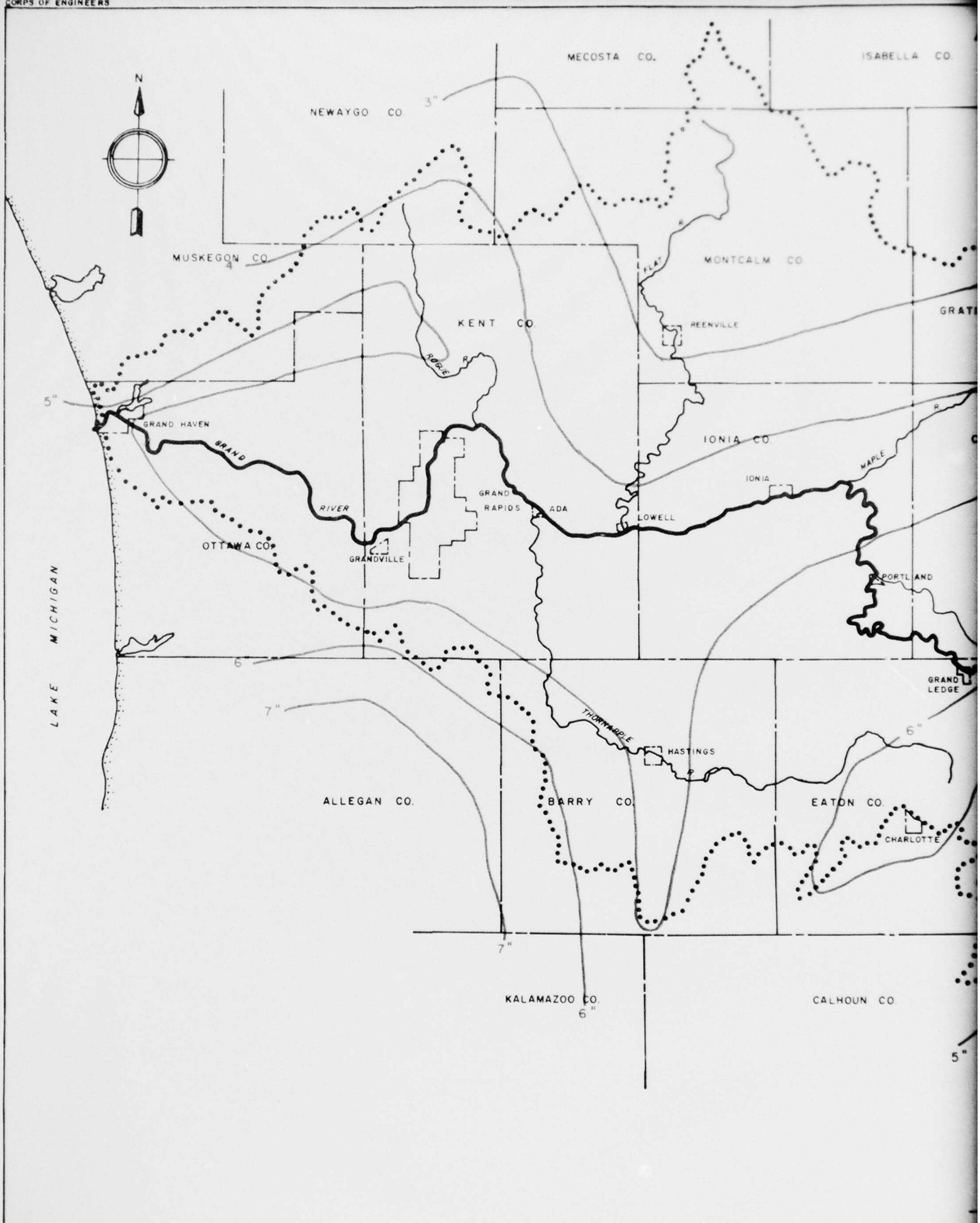


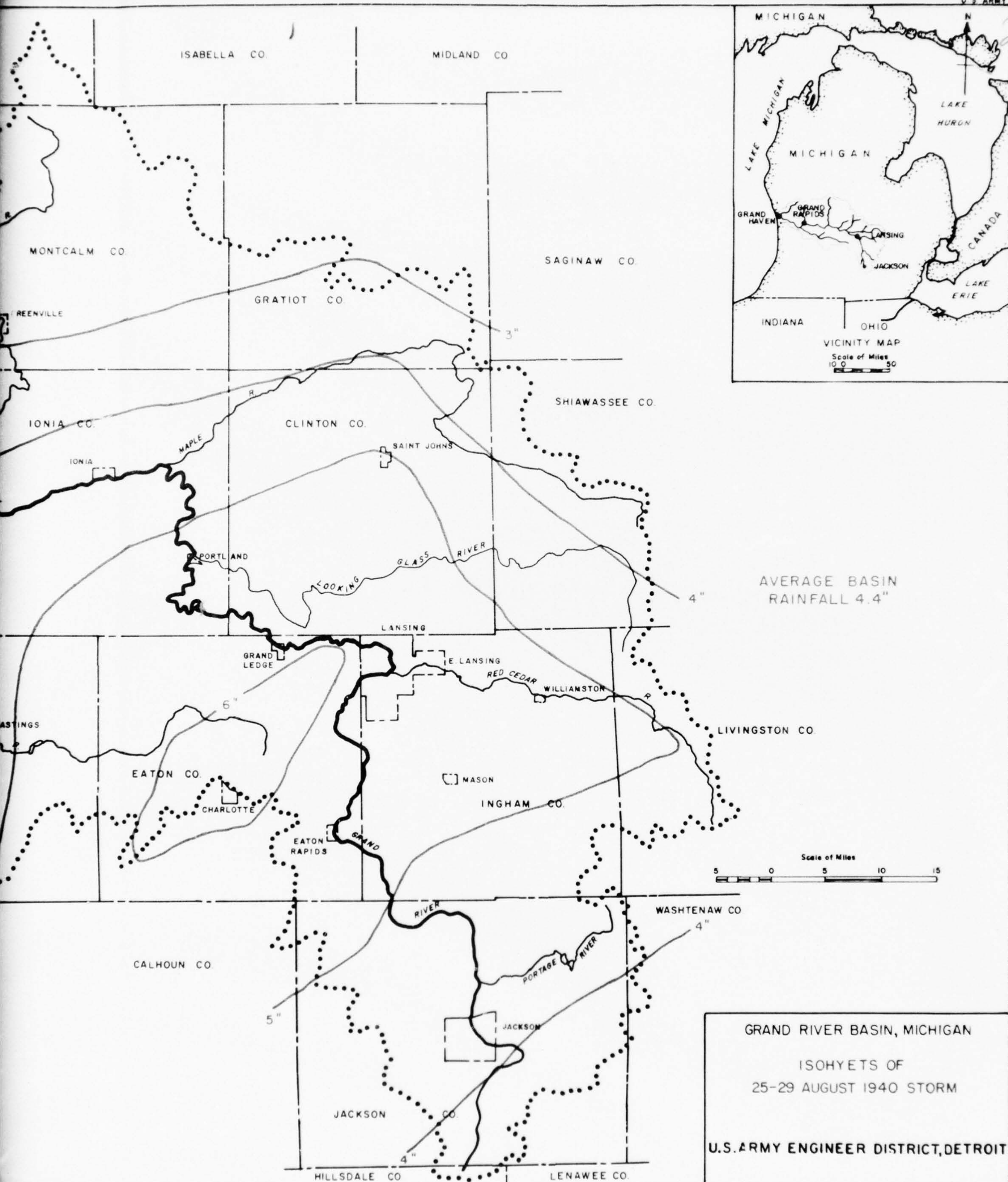
GRAND RIVER BASIN, MICHIGAN

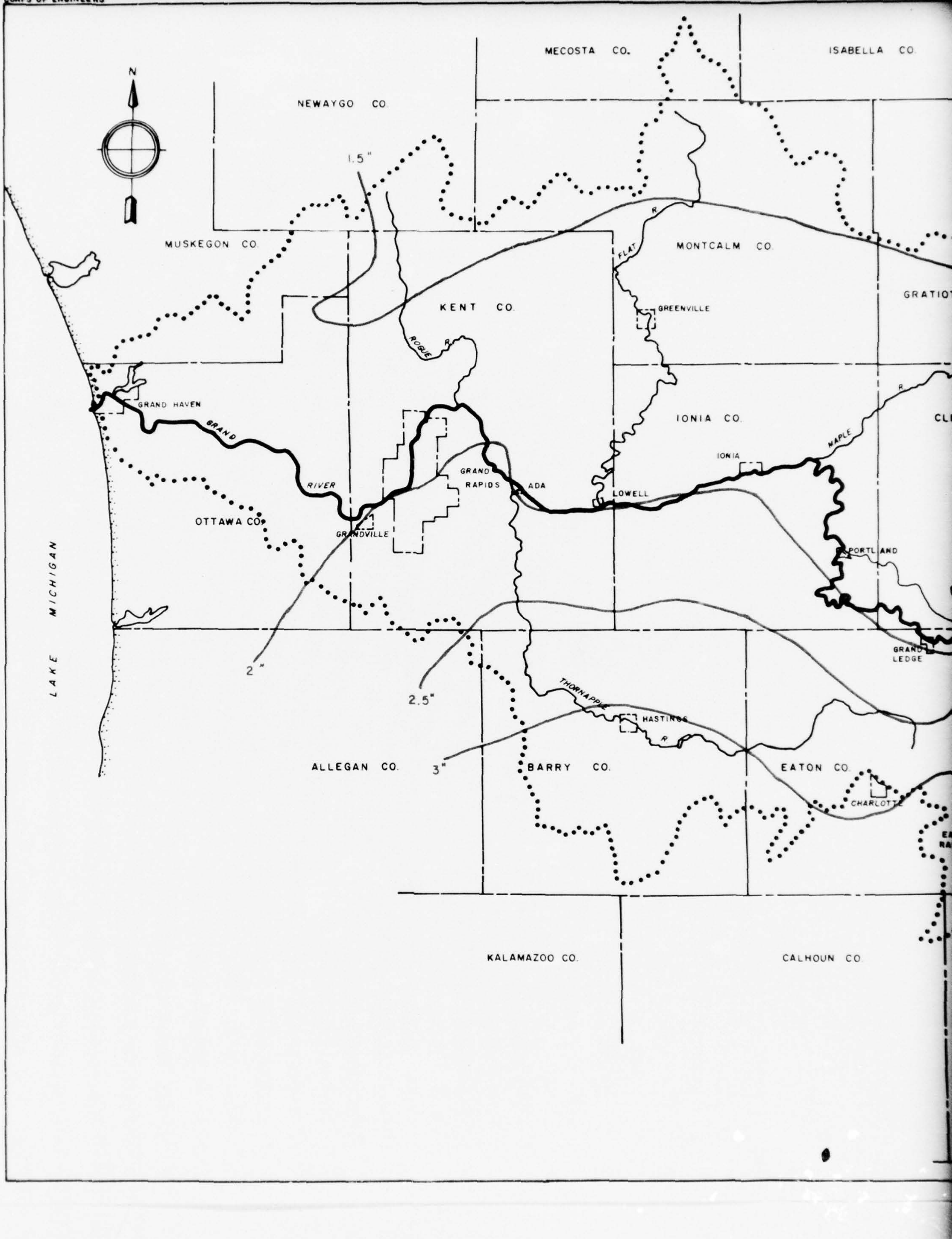
ISOHYETS OF 5-6 JUNE 1905 STORM

U.S. ARMY ENGINEER DISTRICT, DETROIT

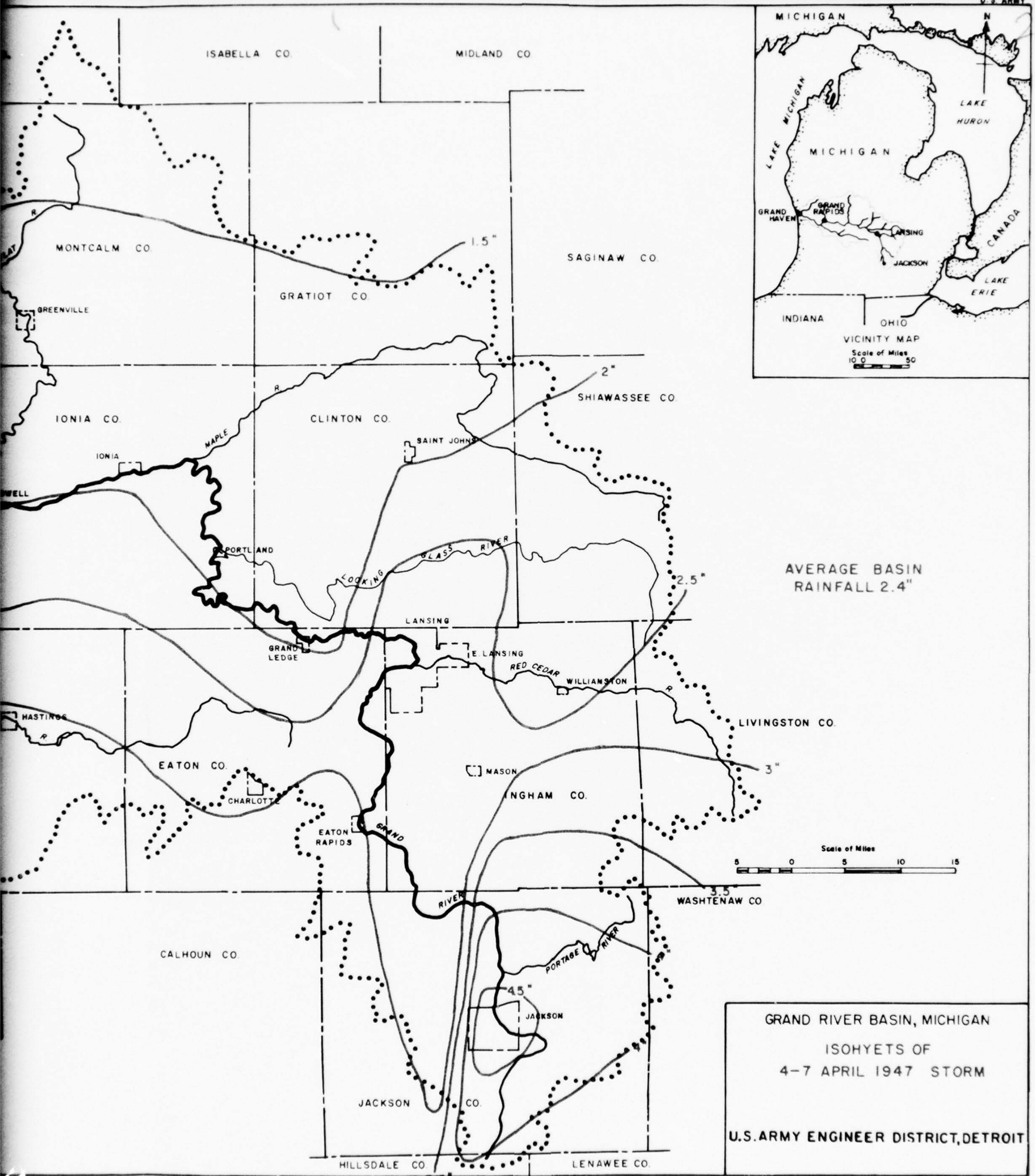
PLATE C-10


N
MECOSTA CO.
ISABELLA CO.
NEWAYGO CO
3"
MUSKEGON CO.
4
MONTCALM CO.
FLAT R
KENT CO
REENVILLE
GRATI
ROGUE R
5"
GRAND HAVEN
GRAND RIVER
IONIA CO.
MAPLE R
IONIA
GRAND RAPIDS
ADA
LOWELL
OTTAWA CO.
GRANDVILLE
PORTLAND
LAKE MICHIGAN
6
GRAND LEDGE
7"
THORNAPPLE R
HASTINGS
6"
ALLEGAN CO.
BARRY CO.
EATON CO.
CHARLOTTE
7"
KALAMAZOO CO.
6"
CALHOUN CO.
5"


U S ARMY
MICHIGAN
N
LAKE MICHIGAN
LAKE HURON
MICHIGAN
GRAND HAVEN
GRAND RAPIDS
LANSING
JACKSON
CANADA
LAKE ERIE
INDIANA
OHIO
VICINITY MAP
Scale of Miles
10 0 50
ISABELLA CO.
MIDLAND CO.
MONTCALM CO.
GRATIOT CO.
SAGINAW CO.
GREENVILLE
3"
IONIA CO.
CLINTON CO.
SHIAWASSEE CO.
MAPLE R
IONIA
SAINT JOHNS
PORTLAND
LOOKING GLASS RIVER
4"
AVERAGE BASIN RAINFALL 4.4"
LANSING
GRAND LEDGE
E. LANSING
RED CEDAR
WILLIAMSTON
R
6"
HASTINGS
LIVINGSTON CO.
EATON CO.
MASON
INGHAM CO.
CHARLOTTE
EATON RAPIDS
GRAND
Scale of Miles
5 0 5 10 15
RIVER
WASHTENAW CO.
4"
CALHOUN CO.
PORTAGE RIVER
5"
JACKSON
JACKSON CO.
4"
HILLSDALE CO.
LENAWEE CO.
GRAND RIVER BASIN, MICHIGAN
ISOHYETS OF
25-29 AUGUST 1940 STORM
U.S. ARMY ENGINEER DISTRICT, DETROIT



N
MECOSTA CO.
ISABELLA CO.
NEWAYGO CO.
1.5"
MUSKEGON CO.
MONTCALM CO.
FLAT R
GRATIOT
KENT CO.
GREENVILLE
ROGUE R
GRAND HAVEN
IONIA CO.
MAPLE R
GRAND
RIVER
IONIA
GRAND
RAPIDS
ADA
LOWELL
OTTAWA CO.
GRANDVILLE
PORTLAND
LAKE MICHIGAN
GRAND LEDGE
2"
2.5"
THORNAPPLE R
HASTINGS
ALLEGAN CO.
3"
BARRY CO.
EATON CO.
CHARLOTTE
KALAMAZOO CO.
CALHOUN CO.

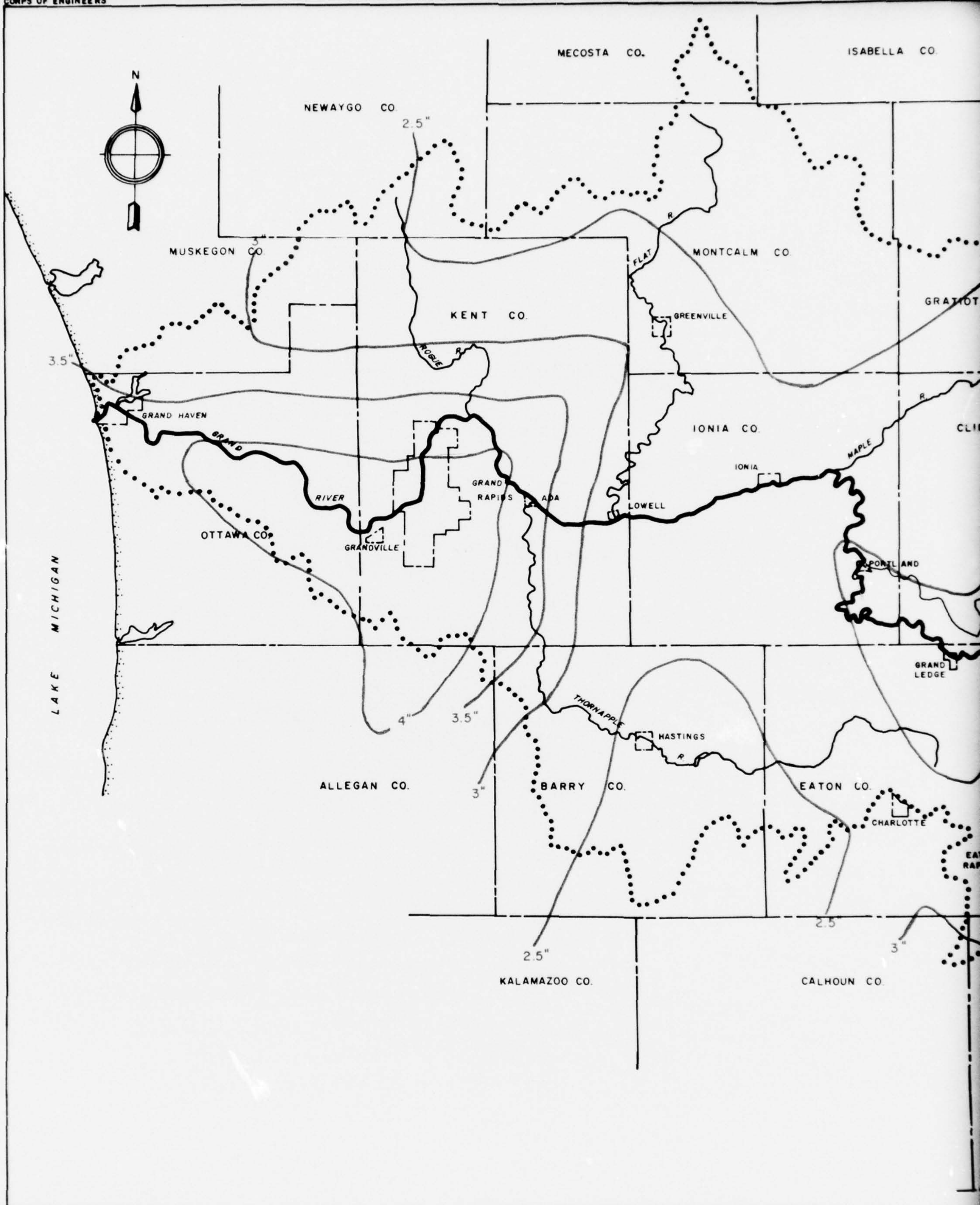


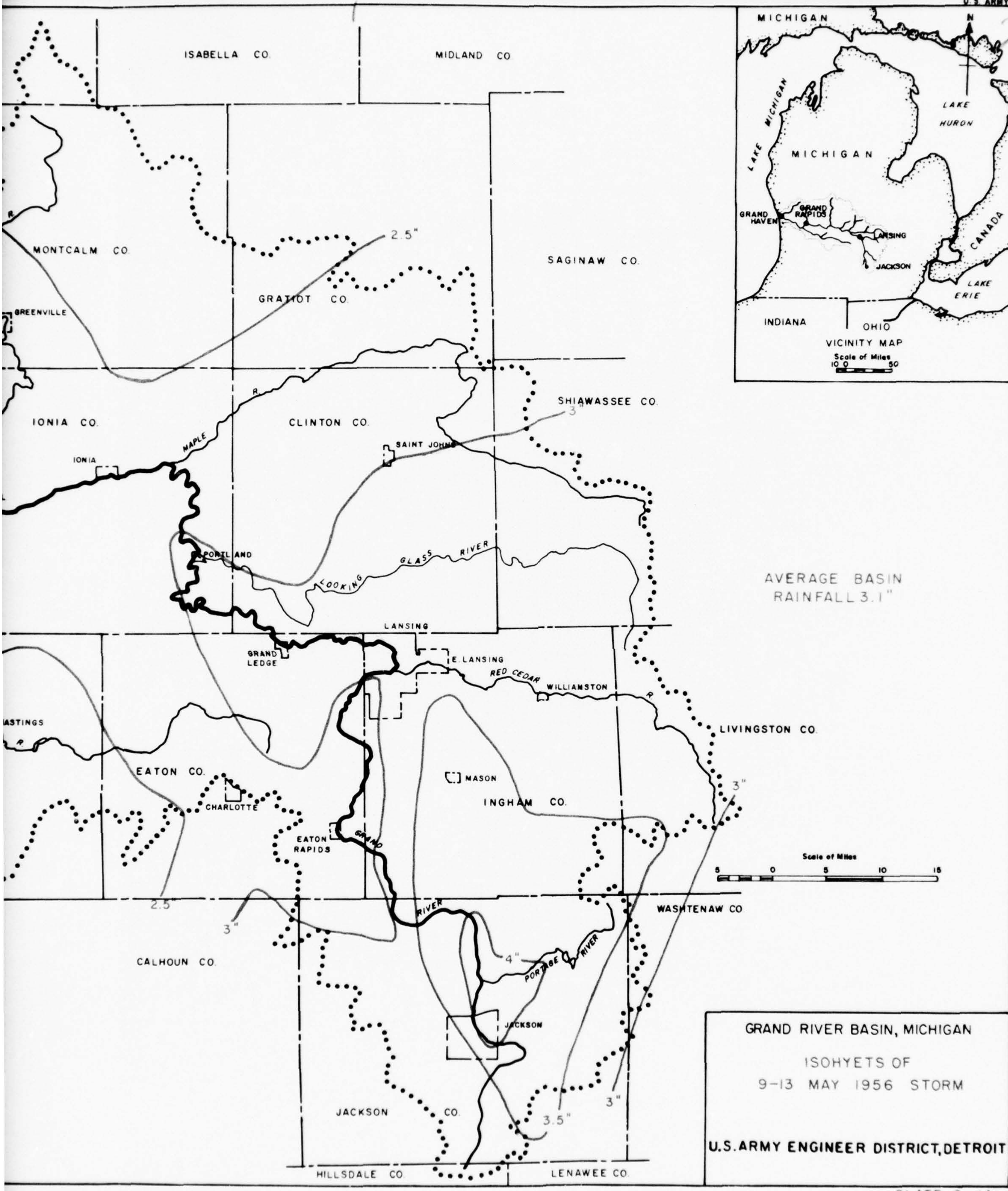
GRAND RIVER BASIN, MICHIGAN

ISOHYETS OF

4-7 APRIL 1947 STORM

U.S. ARMY ENGINEER DISTRICT, DETROIT


N
MECOSTA CO.
ISABELLA CO.
NEWAYGO CO.
2.5"
MUSKEGON CO.
3"
FLAT R
MONTCALM CO.
KENT CO.
GREENVILLE
GRATIOT
3.5"
ROGUE R
GRAND HAVEN
GRAND
IONIA CO.
CLIN
MAPLE R.
IONIA
GRAND RAPIDS
ADA
LOWELL
RIVER
OTTAWA CO.
GRANDVILLE
PORTLAND
LAKE MICHIGAN
GRAND LEDGE
THORNAPPLE R
HASTINGS
4"
3.5"
3"
ALLEGAN CO.
BARRY CO.
EATON CO.
CHARLOTTE
2.5"
3"
2.5"
KALAMAZOO CO.
CALHOUN CO.

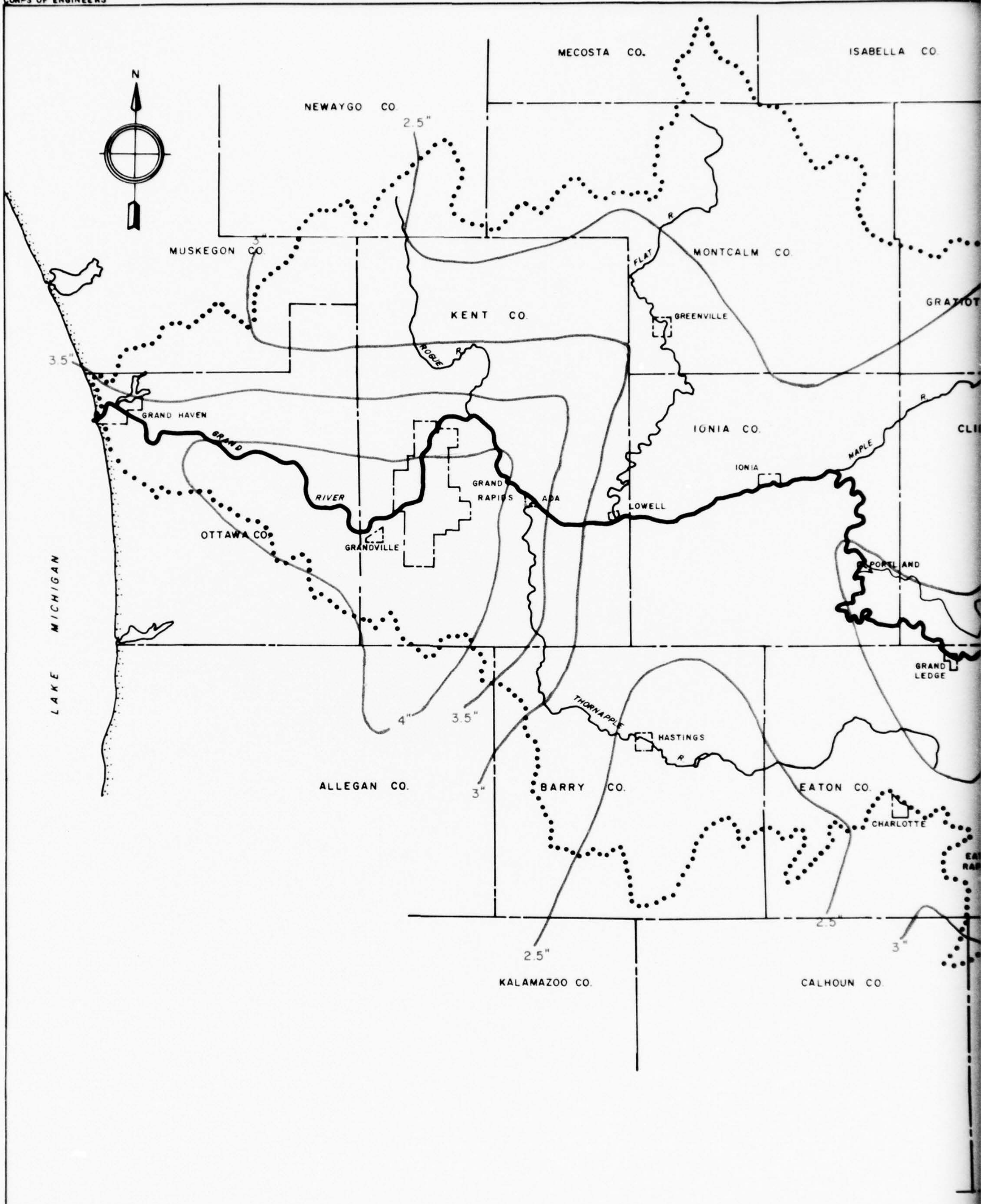


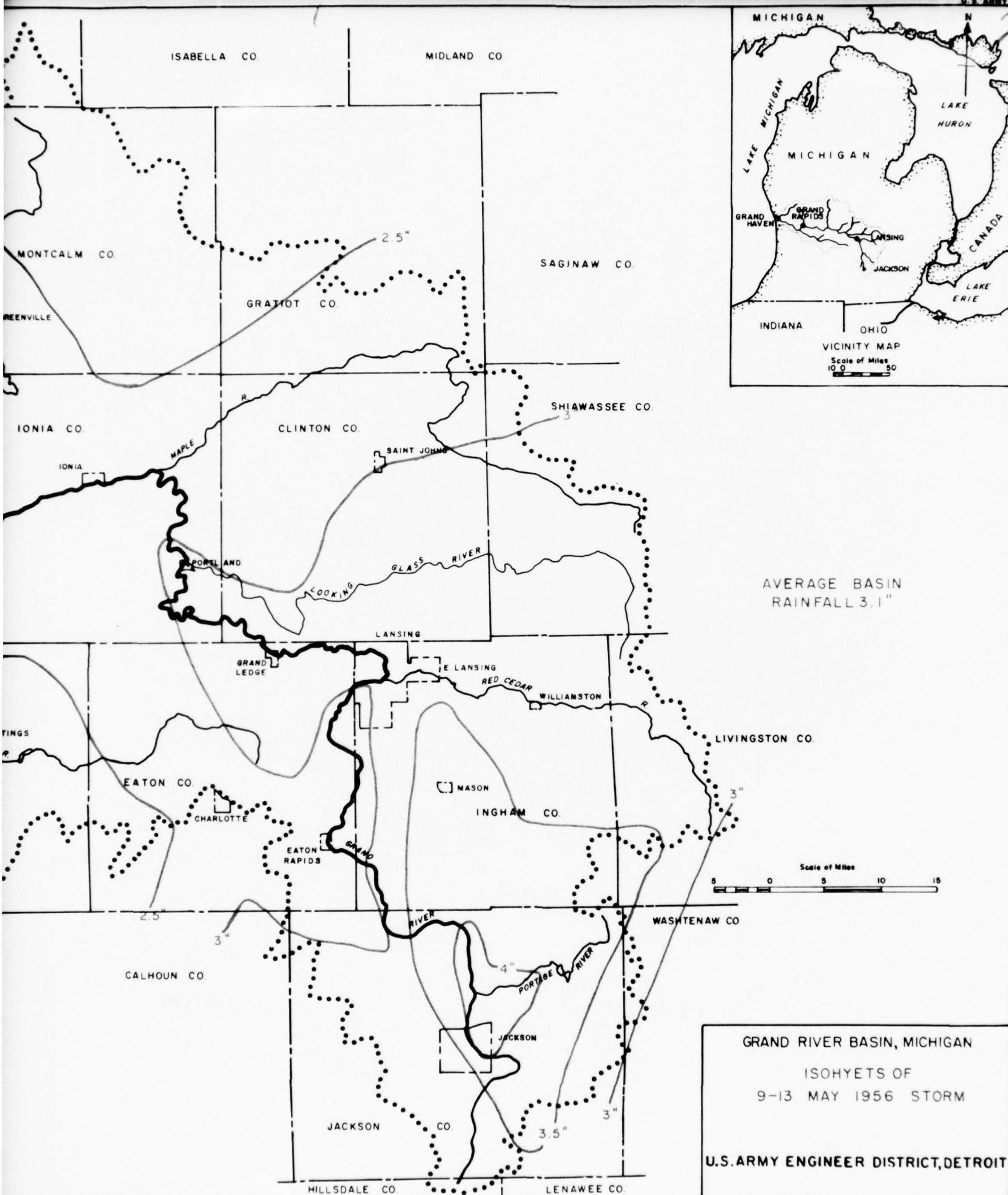
GRAND RIVER BASIN, MICHIGAN

ISOHYETS OF 9-13 MAY 1956 STORM

U.S. ARMY ENGINEER DISTRICT, DETROIT

PLATE C-14


N
MECOSTA CO.
ISABELLA CO.
NEWAYGO CO.
2.5"
MUSKEGON CO.
3"
MONTCALM CO.
FLAT
R
KENT CO.
GREENVILLE
GRATIOT
ROGUE
R
3.5"
GRAND HAVEN
IONIA CO.
MAPLE
R.
GRAND
RIVER
GRAND
RAPIDS
ADA
LOWELL
IONIA
OTTAWA CO.
GRANDVILLE
PORTLAND
LAKE MICHIGAN
GRAND
LEDGE
THORNAPPLE
R
HASTINGS
4"
3.5"
3"
ALLEGAN CO.
BARRY CO.
EATON CO.
CHARLOTTE
2.5"
3"
2.5"
KALAMAZOO CO.
CALHOUN CO.



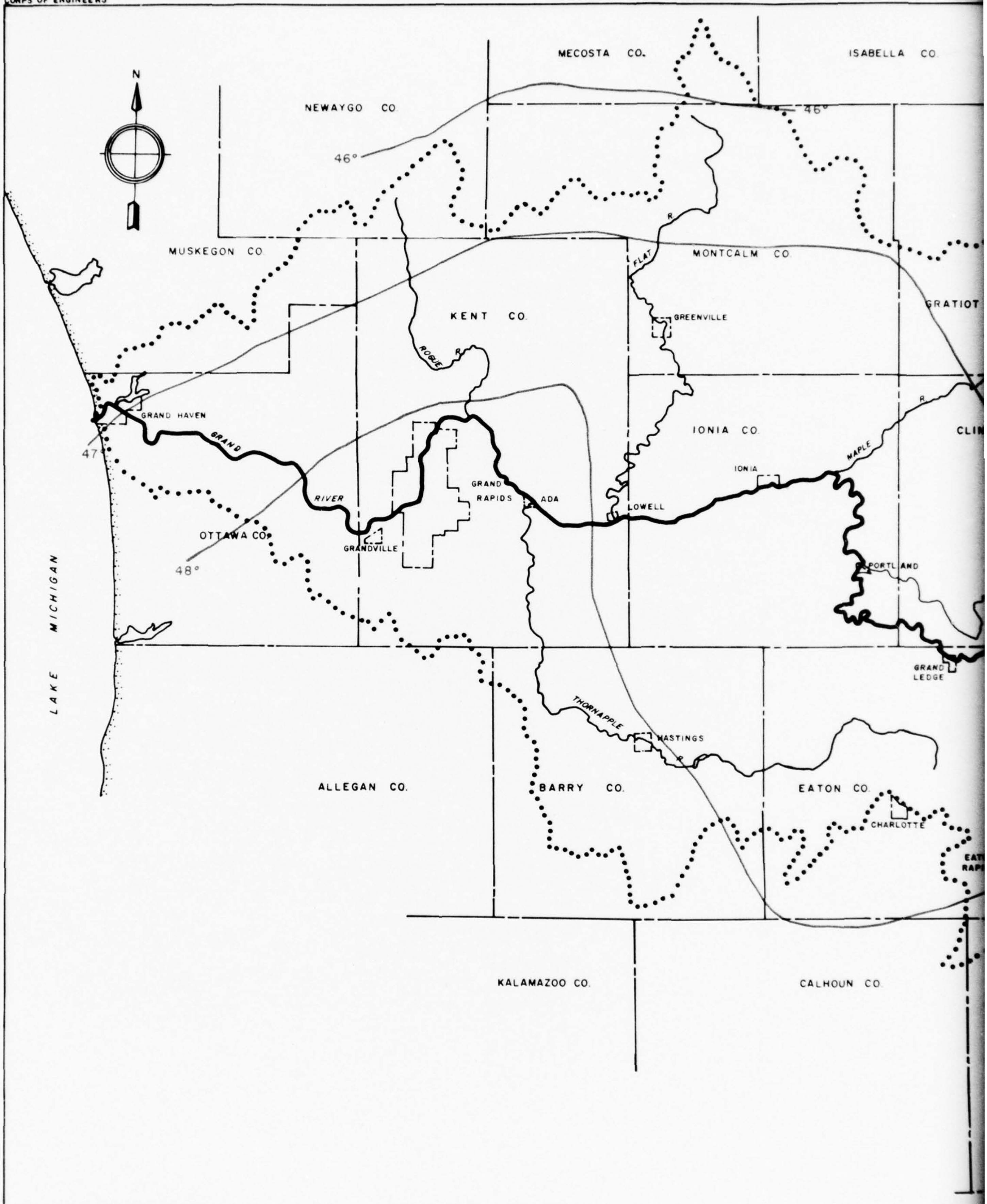
GRAND RIVER BASIN, MICHIGAN

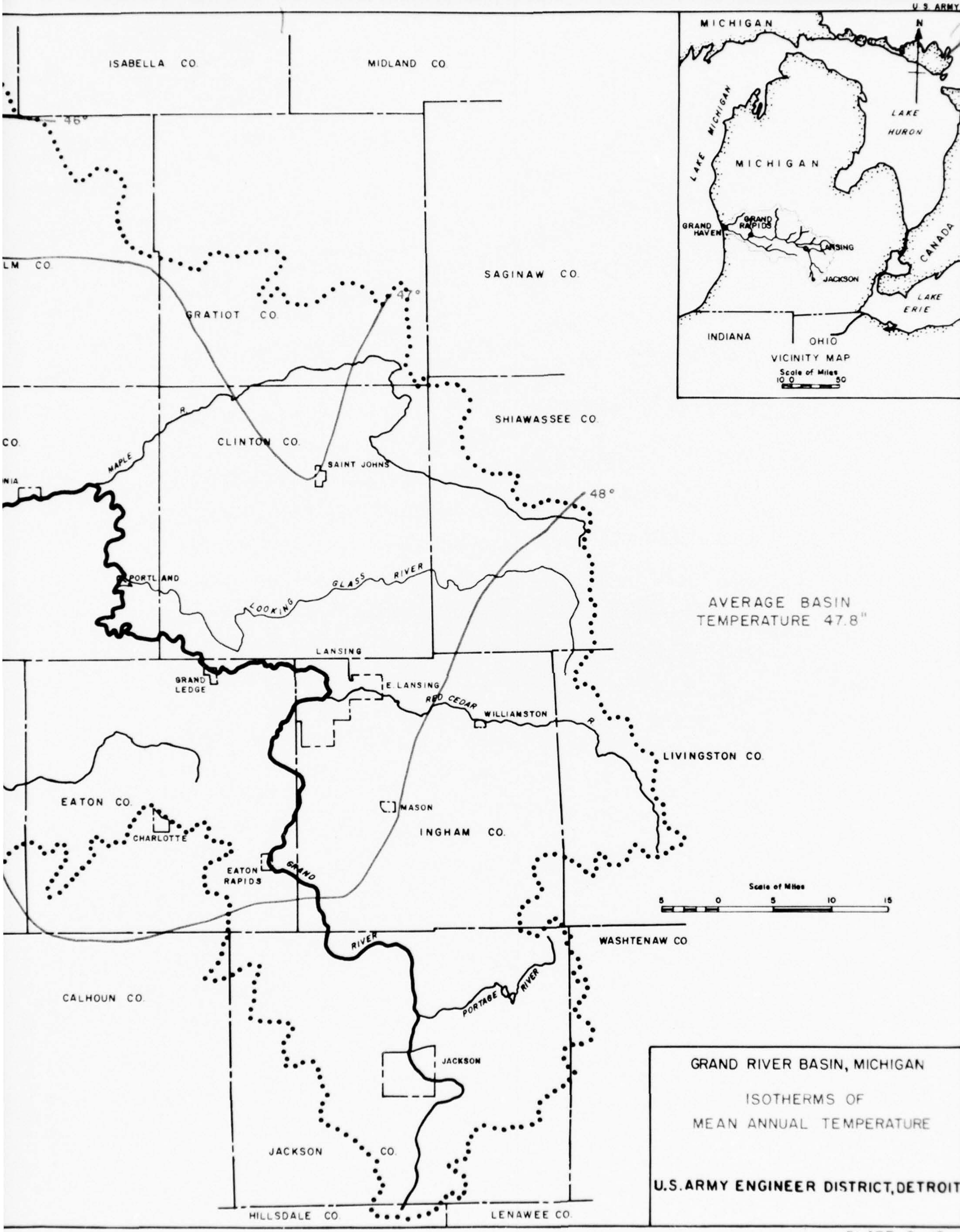
ISOHYETS OF
9-13 MAY 1956 STORM

U.S. ARMY ENGINEER DISTRICT, DETROIT

PLATE C-14

CORPS OF ENGINEERS





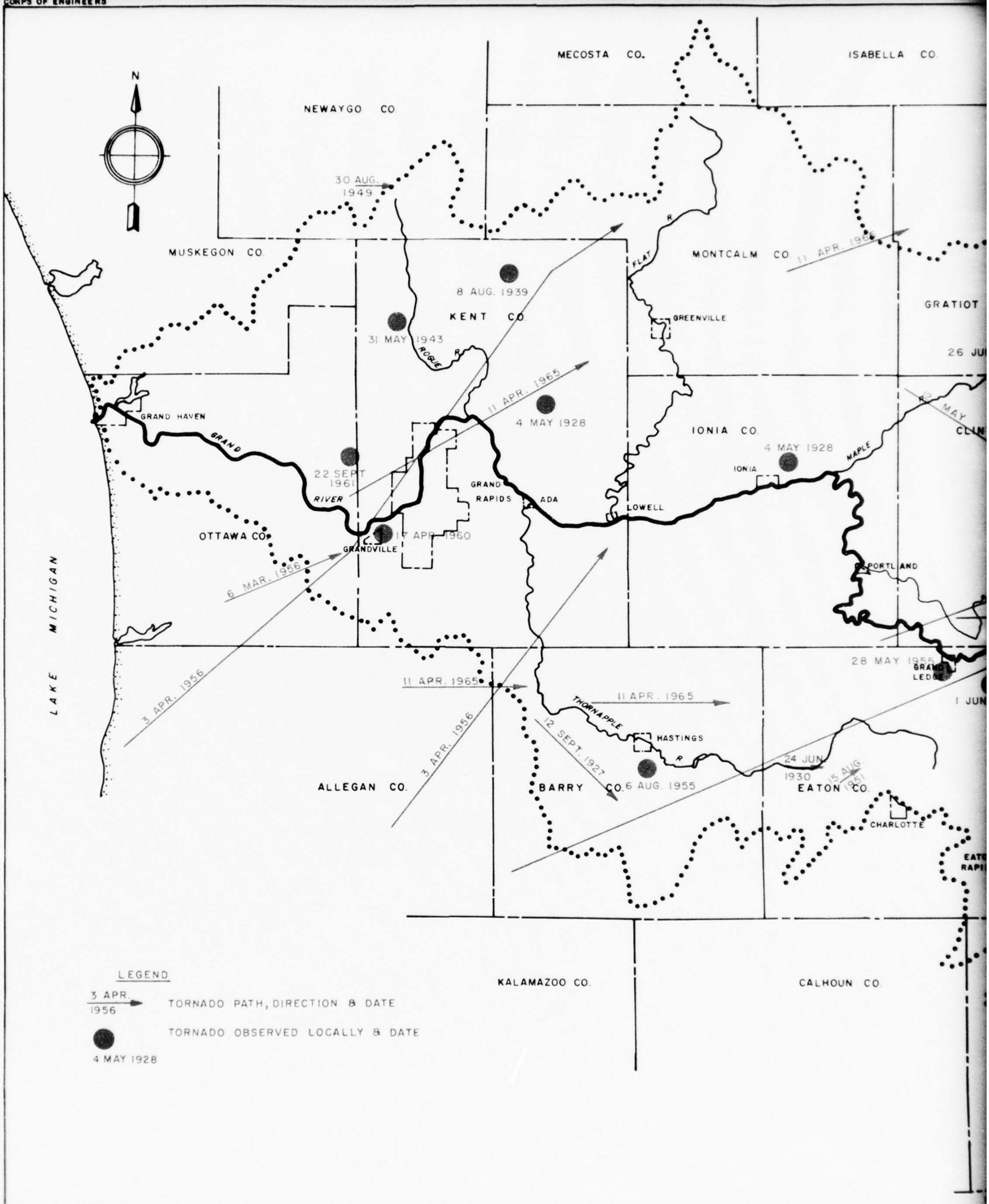
GRAND RIVER BASIN, MICHIGAN

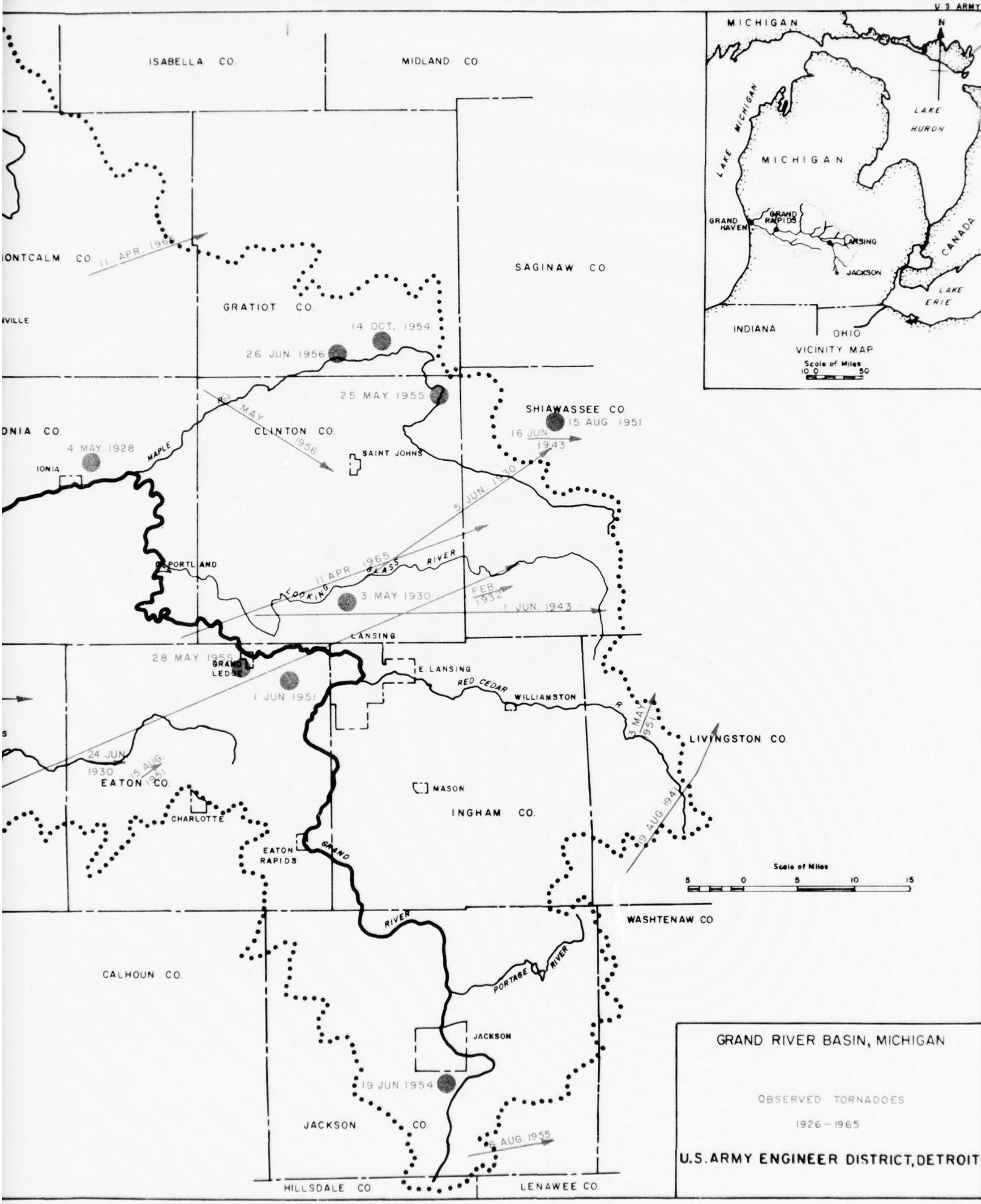
ISOTHERMS OF
MEAN ANNUAL TEMPERATURE

U.S. ARMY ENGINEER DISTRICT, DETROIT

PLATE C-15

CORPS OF ENGINEERS



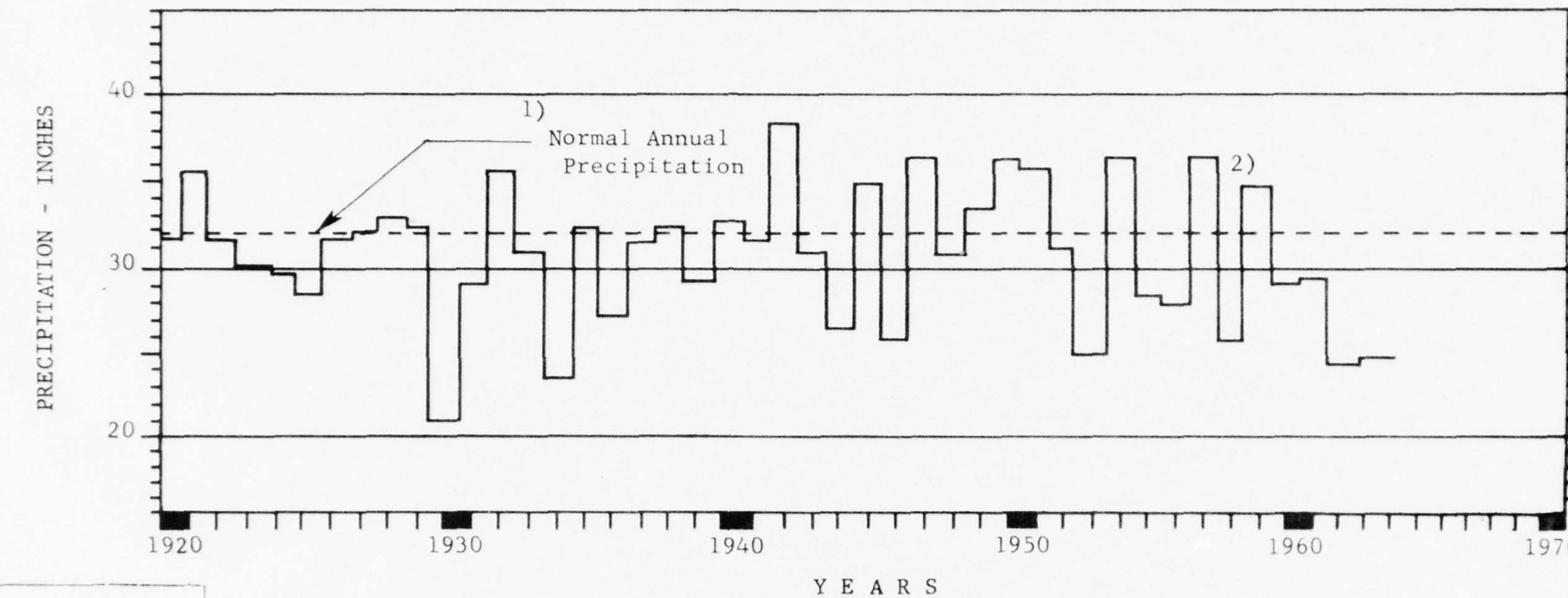


GRAND RIVER BASIN, MICHIGAN

OBSERVED TORNADOES

1926 – 1965

U.S. ARMY ENGINEER DISTRICT, DETROIT



1) Normal annual Basin precipitation based on U.S. Weather Bureau records located within and near the Basin with at least 50 years of record.

2) Annual Basin precipitation amounts based on records compiled at most U.S. Weather Bureau stations operating within the Basin during any given year.

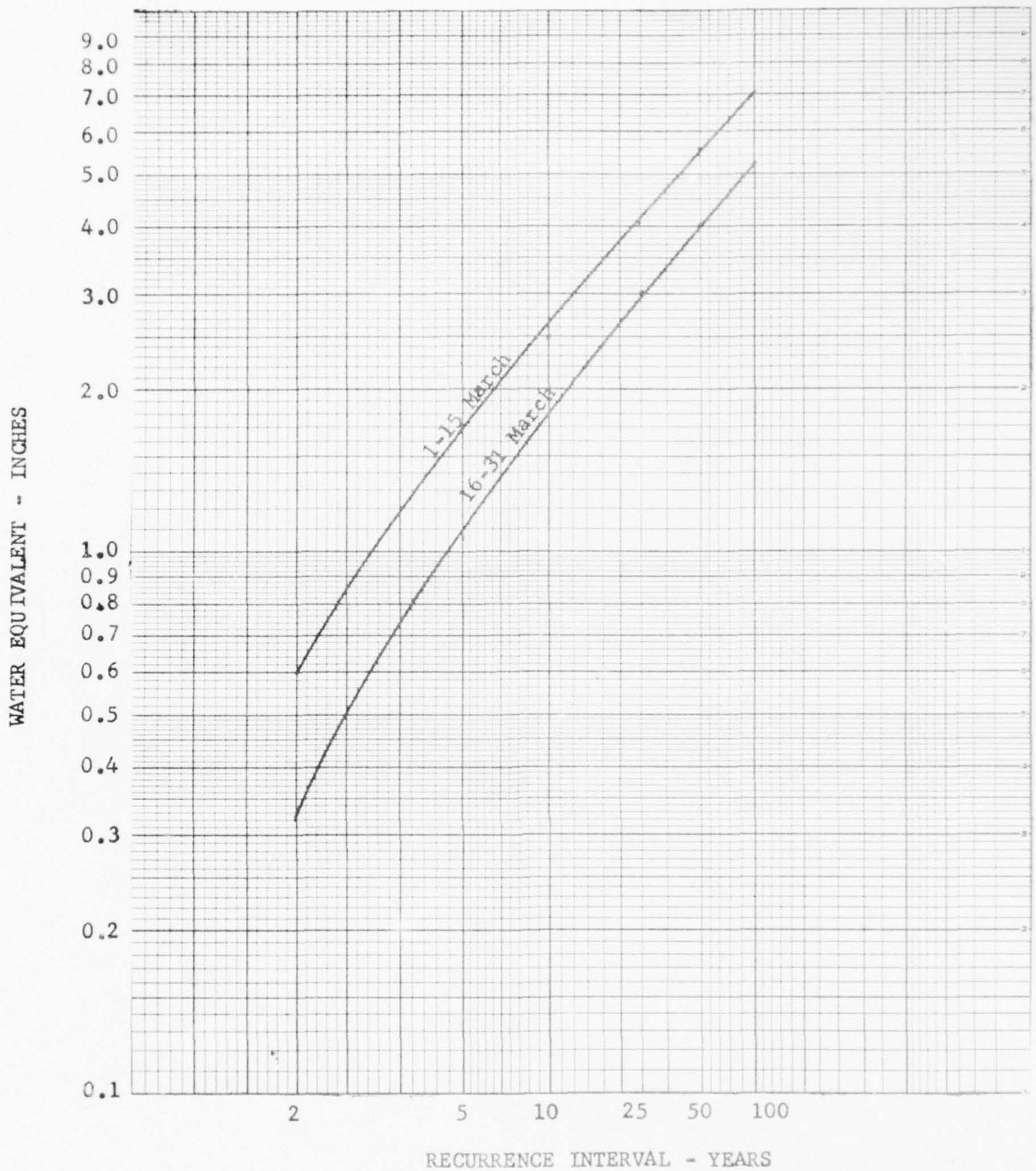
GRAND RIVER BASIN

ANNUAL PRECIPITATION

1920-1963

U.S. ARMY ENGINEER DISTRICT, DETROIT

FIGURE C-1



Data obtained from U.S. Weather Bureau T.P. No. 50 - Frequency of Maximum Water Equivalent of March Snow Cover in North Central United States - 1964

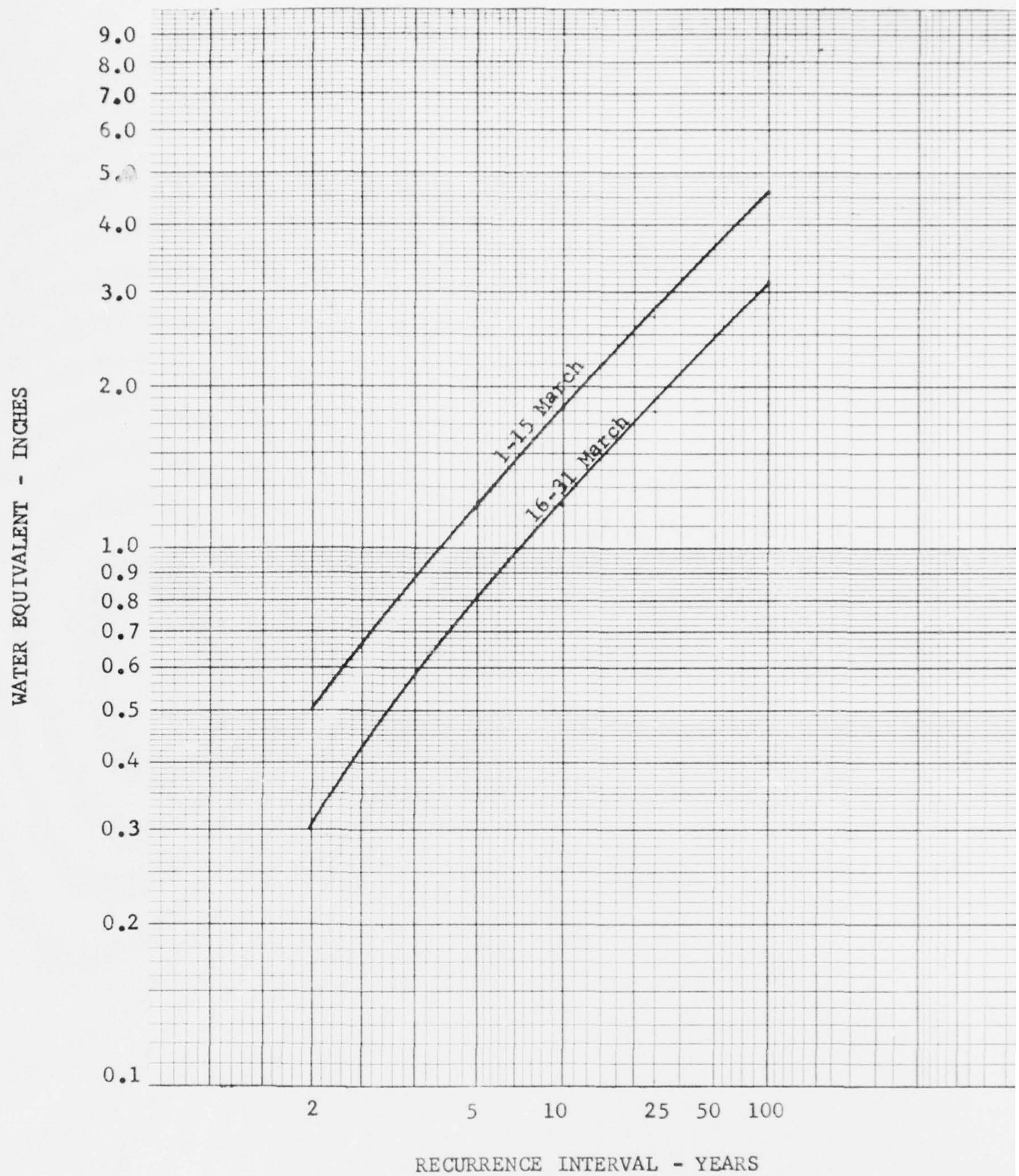
GRAND RIVER BASIN, MICHIGAN

FREQUENCY OF MAXIMUM WATER EQUIVALENT OF MARCH SNOW COVER

GRAND RAPIDS

U.S. ARMY ENGINEER DISTRICT, DETROIT

FIGURE C-2



Data obtained from U.S. Weather Bureau T.P. No. 50 - Frequency of Maximum Water Equivalent of March Snow Cover in North Central United States - 1964

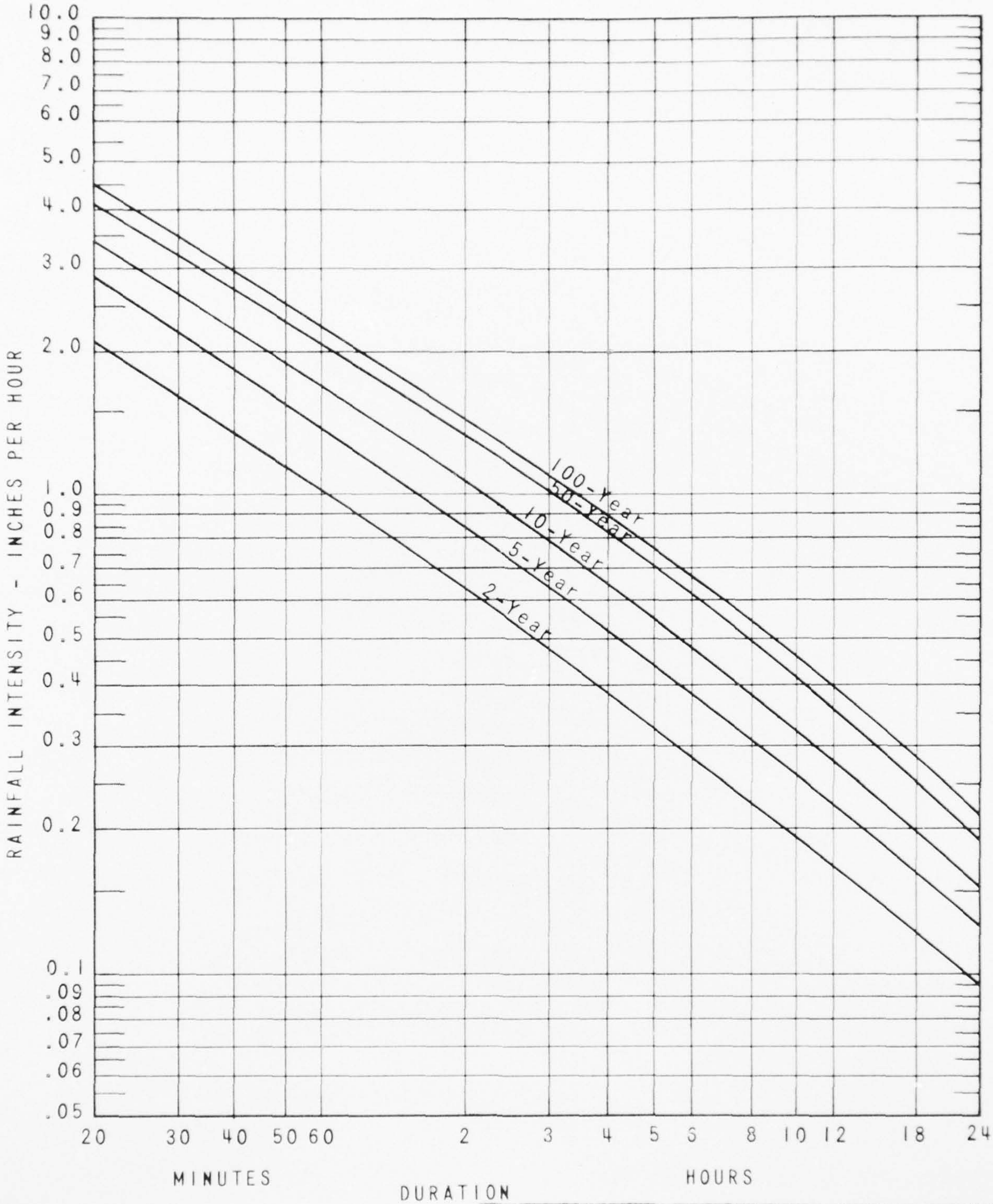
GRAND RIVER BASIN, MICHIGAN

FREQUENCY OF MAXIMUM WATER EQUIVALENT OF MARCH SNOW COVER

LANSING

U.S. ARMY ENGINEER DISTRICT, DETRO

FIGURE C-3



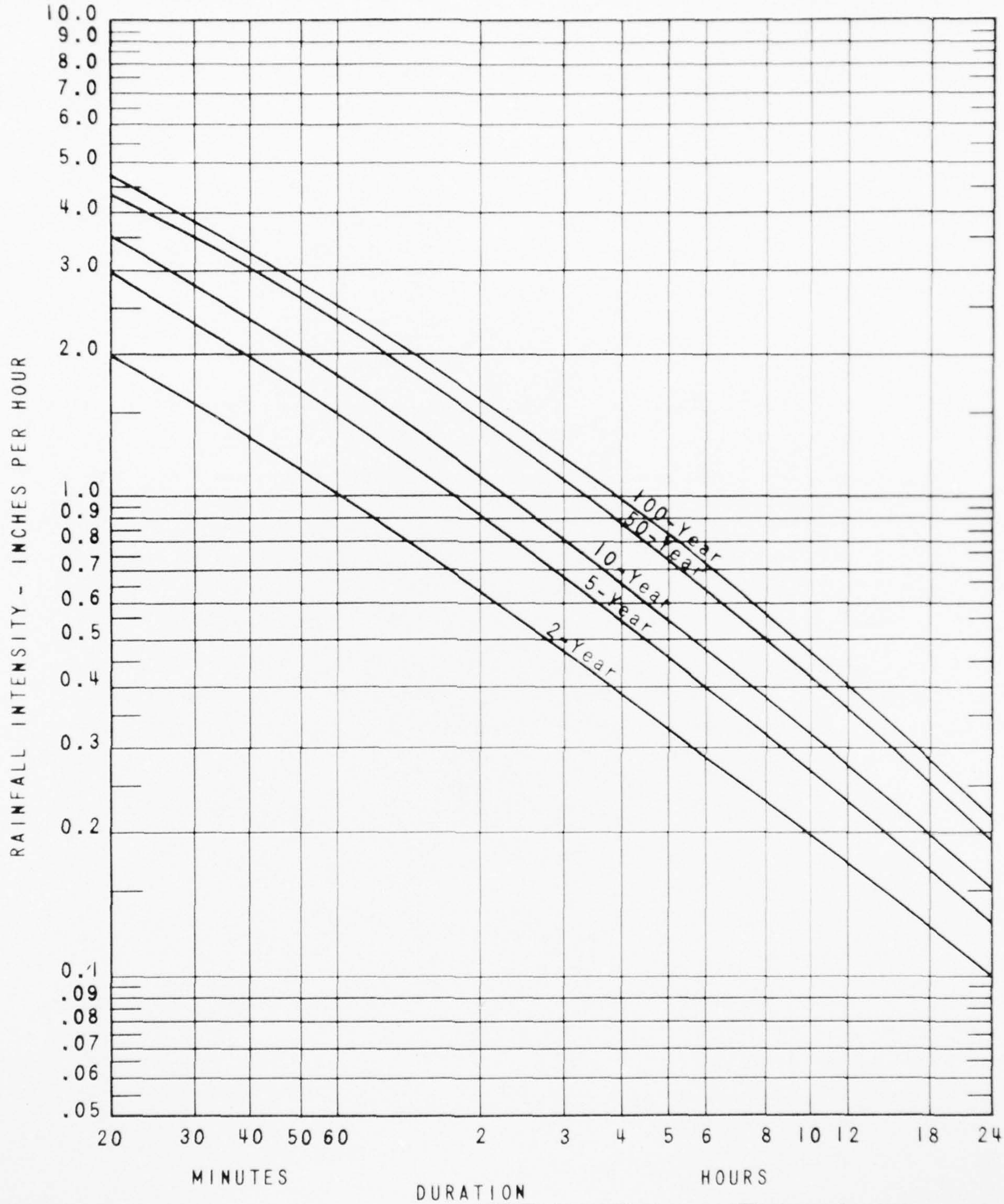
Data taken from U.S. Weather Bureau T.P.No.29 - Rainfall-Frequency Regime-Part 5-Great Lakes Region - 1960

GRAND RIVER BASIN, MICHIGAN
RAINFALL
INTENSITY-DURATION-FREQUENCY

GRAND HAVEN 1906-1932

U.S. ARMY ENGINEER DISTRICT, DETROIT

FIGURE C-4



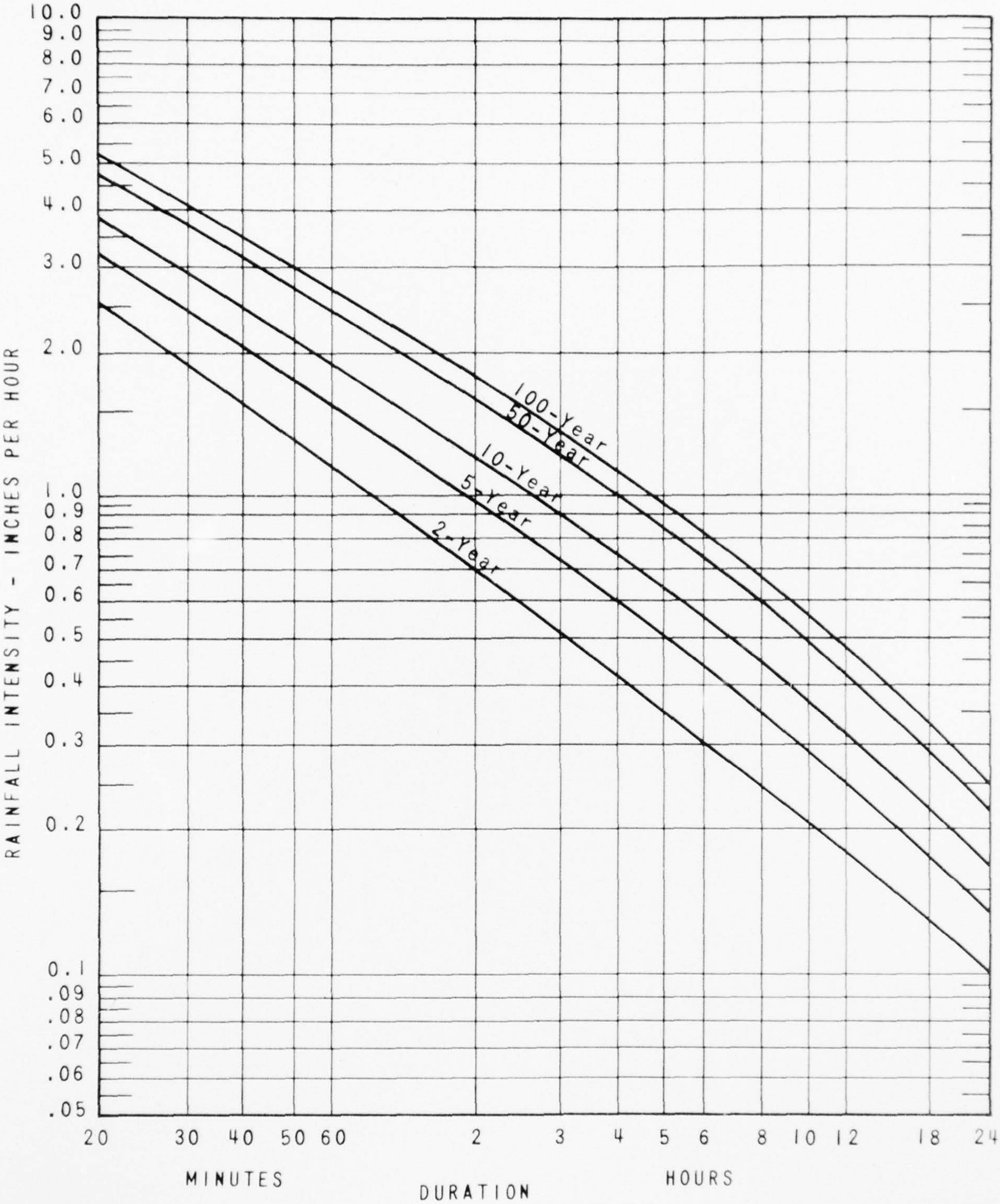
Data taken from U.S. Weather Bureau T.P. No. 29 - Rainfall-Frequency Regime - Part 5 - Great Lakes Region - 1960

GRAND RIVER BASIN, MICHIGAN
RAINFALL
INTENSITY-DURATION-FREQUENCY

GRAND RAPIDS 1905-1957

U.S. ARMY ENGINEER DISTRICT, DETROIT

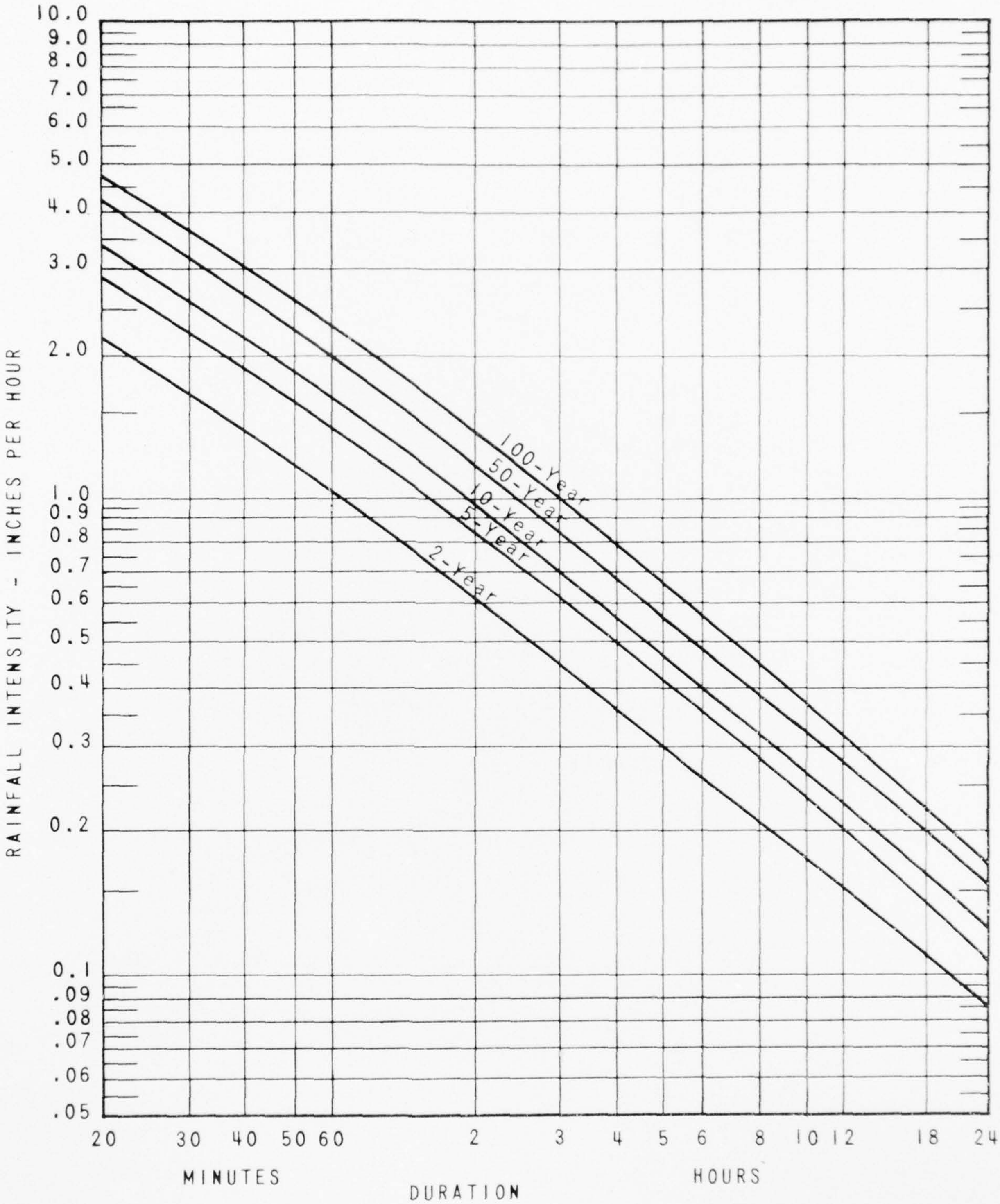
FIGURE C-5



Data taken from U.S. Weather Bureau T.P. No. 20 - Rainfall-Frequency Regime - Part 5 - Great Lakes Region - 1960

GRAND RIVER BASIN, MICHIGAN
RAINFALL
INTENSITY-DURATION-FREQUENCY
JACKSON 1905-1957
U.S. ARMY ENGINEER DISTRICT, DETROIT

FIGURE C-6



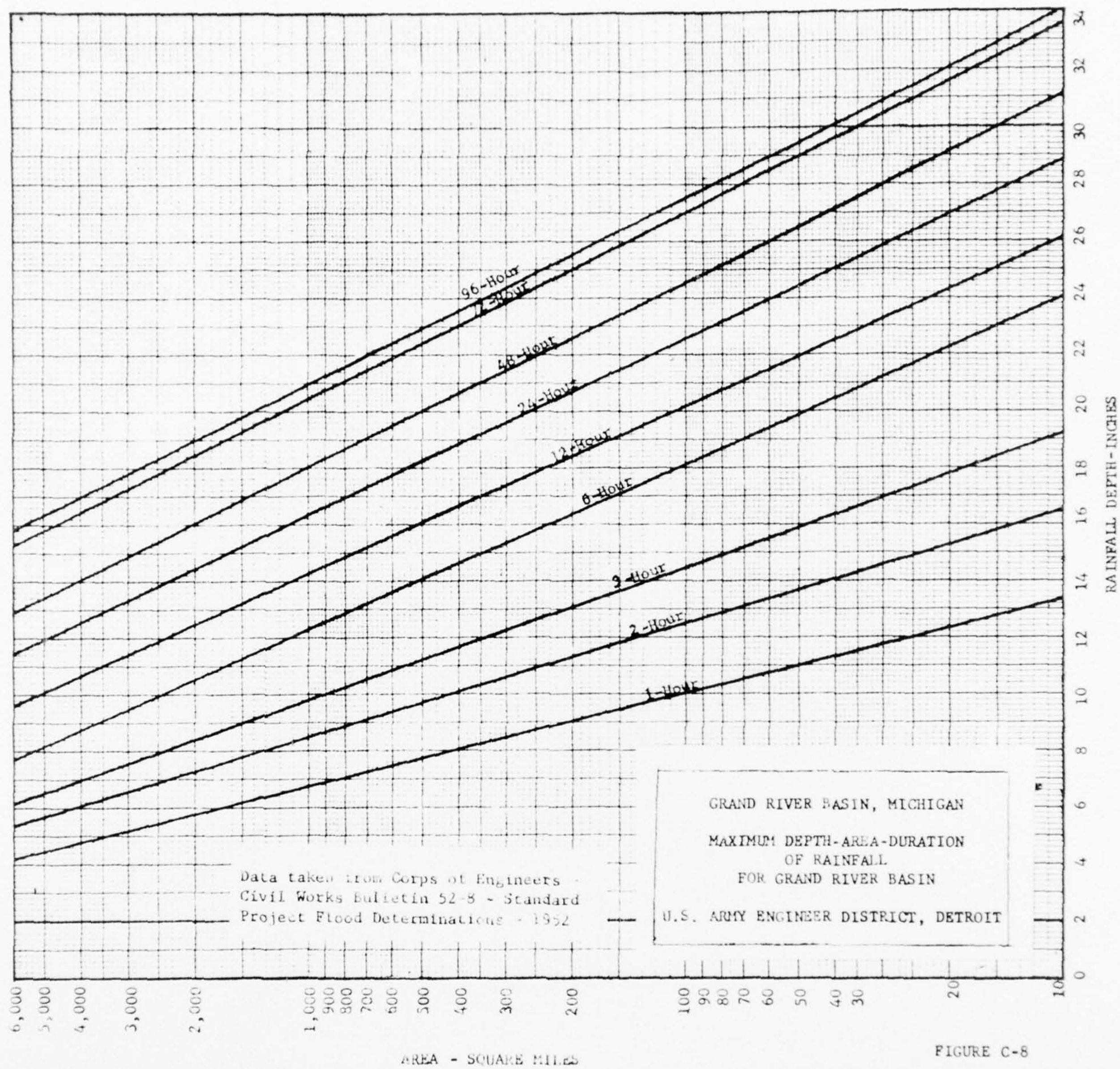
Data taken from U.S. Weather Bureau T.P. No. 29 - Rainfall-Frequency Regime - Part 5 - Great Lakes Region - 1960

GRAND RIVER BASIN, MICHIGAN
RAINFALL
INTENSITY-DURATION-FREQUENCY

LANSING 1910-1957

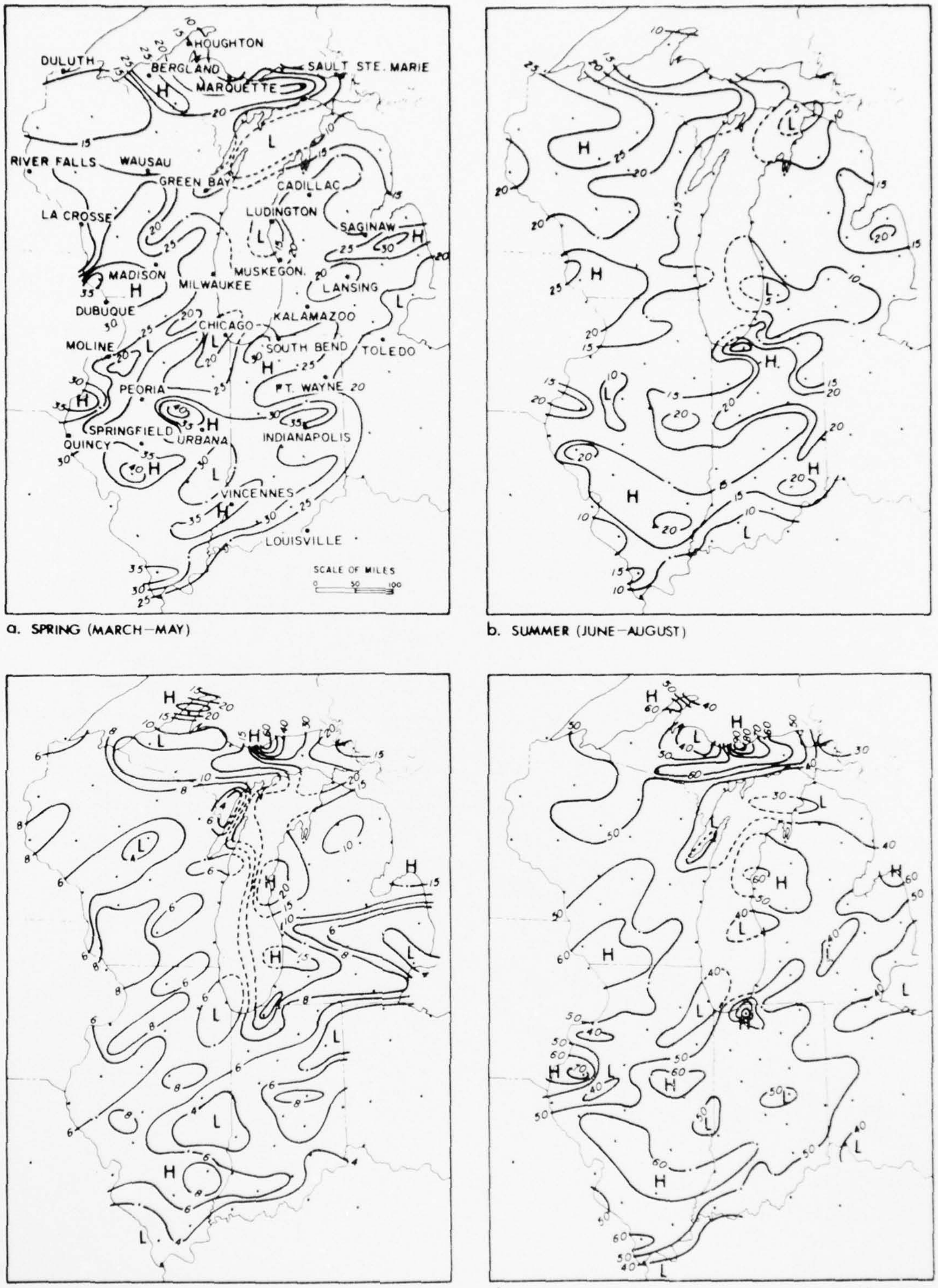
U.S. ARMY ENGINEER DISTRICT, DETROIT

FIGURE C-7



96-Hour
72-Hour
48-Hour
24-Hour
12-Hour
6-Hour
3-Hour
2-Hour
1-Hour
RAINFALL DEPTH-INCHES
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
6,000
5,000
4,000
3,000
2,000
1,000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
Data taken from Corps of Engineers -
Civil Works Bulletin 52-8 - Standard
Project Flood Determinations - 1952
GRAND RIVER BASIN, MICHIGAN
MAXIMUM DEPTH-AREA-DURATION
OF RAINFALL
FOR GRAND RIVER BASIN
U.S. ARMY ENGINEER DISTRICT, DETROIT
AREA - SQUARE MILES

FIGURE C-8



a. SPRING (MARCH–MAY)

b. SUMMER (JUNE–AUGUST)

c. FALL (SEPTEMBER–NOVEMBER)

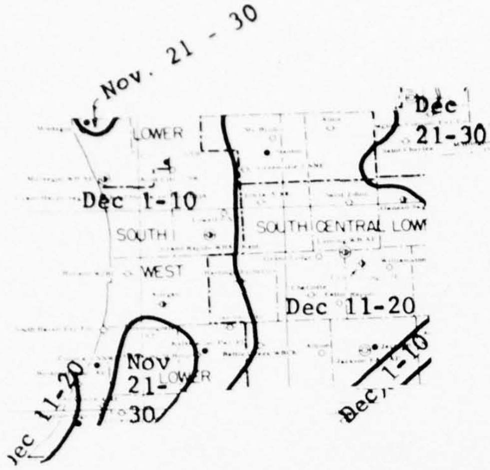
d. TOTAL NUMBER OF HAIL DAYS IN AN AVERAGE 20-YEAR PERIOD

NUMBER OF HAIL DAYS IN AVERAGE 20-YEAR PERIOD

REFERENCE: SUMMARY OF HAIL RESEARCH IN ILLINOIS

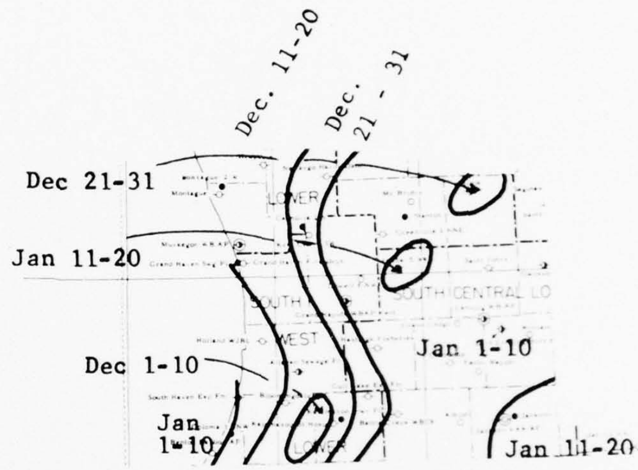
ILLINOIS STATE WATER SURVEY DECEMBER 29, 1966

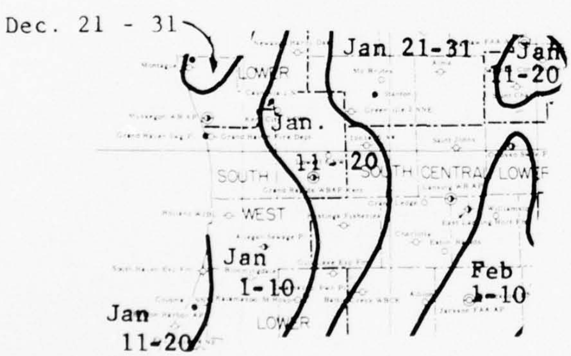
FIGURE C-9



Mean Date of First 3-inch Snow Depth

Mean Date of First 6-inch Snow Depth





Mean Date of First 12-inch Snow Depth

REFERENCE: MICHIGAN SNOW DEPTHS
ESSA - WEATHER BUREAU
FEBRUARY 1969

GRAND RIVER BASIN

MEAN DATES OF 3-, 6-, AND 12 - INCH

SNOW DEPTHS

U. S. ARMY ENGINEER DISTRICT, DETROIT

FIGURE C-10

APPENDIX D

SURFACE WATER HYDROLOGY AND HYDRAULICS
AND FLUVIAL SEDIMENT

GRAND RIVER BASIN
COMPREHENSIVE PLANNING STUDY

Compiled by the
U. S. Army Engineer District, Detroit
Corps of Engineers

APPENDIX D

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GRAND RIVER BASIN MICHIGAN. COMPREHENSIVE WATER RESOURCES STUDY--ETC(U)
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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

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SUMMARY

The Grand River and seven major tributaries and more than 1,000 lakes comprise the major portion of the Basin's surface waters. Virturally all data collected for surface waters relate to streamflows. Streamflows are subject to daily and seasonal variations. Above average annual flows are generally prevalent during the late winter, spring, and early summer months of February through June, while below average annual flows are generally prevalent during the late summer, fall, and early winter months of July through January. The degree of variation in streamflows is dependent on the physiographic and climatic conditions of the Basin during these periods. The normal daily discharge within the Basin is about 0.5 cubic feet per second per square mile of drainage area (c.f.s.m.). Normal daily flows within the Basin vary from 0.2 c.f.s.m. to 0.7 c.f.s.m. The Thornapple, Rogue and Flat Rivers have the highest yields, while the Lookingglass, Maple and Red Cedar Rivers have the lowest yields. The longest period of sustained below-average annual flows experienced throughout the Basin is five years. Significant Basin-wide flood conditions exist when about 1.5 inches of runoff occur, and normally are experienced during the late winter and early spring months of February through April. These floods occur about once in 40 years. Localized floods are normally experienced each year during the late spring and early summer months of May through July. The most noteworthy Basin flood characteristics are that the Grand River peak flows at Lansing are, for the most part, coincidental with the peak flows from the Red Cedar River excluding the Portage River flows and the runoff from the area upstream of Jackson. Grand River peak flows at Lansing do not usually contribute significantly to the peak flows at Grand Rapids. Periods of deficient precipitation and low flow periods coincide; low flow periods exist over the entire Basin. Evapotranspiration losses

normally exceed 30 inches per year. Infiltration rates vary from 0.04 inches per hour to 0.18 inches per hour during the late winter and early spring months of January to May. The infiltration rates vary from 0.18 inches per hour to over 1.00 inch per hour during the late spring and early summer months of May to August. The existing flood forecasting system for the Basin appears to be adequate at this time. Inclusion of a water resource project will require an extension of this forecasting system for the efficient and safe operation of the project. Fluvial sedimentation rates vary considerably throughout the Basin. Stream bed sediment loads are not excessive, but reservoir sizes and shapes are determining factors in evaluating reservoir capacity losses due to deposition of fluvial and organic sediments. Sediment accumulations would probably reduce storage capacities by 15 to 40 percent over a 100 year period in medium to shallow depth reservoirs.

SECTION I
INTRODUCTION

1. SCOPE

Formulation of a comprehensive plan for the development of the waters of the Grand River Basin requires extensive data on the several pertinent subdivisions of hydrology of the Basin. These subdivisions are:

a. Flow frequency of instantaneous flood peaks.

b. Low flow rates and volumes.

c. Flood and low flow characteristics.

d. Surface water losses due to evapotranspiration and infiltration.

e. Flood forecasting system and future requirements.

f. The origin, movement, deposition and trends of fluvial sediments.

The purpose of Appendix D is to present data on these subdivisions that are sufficient for Basin plan formulation. Also presented is a description of the Basin Flood forecasting system and duture necessary requirements of that system.

Inherent in this appendix is a lag-in-time between the period when the bulk of studies were made, years 1964 to 1967, and completion of the comprehensive study. It was necessary that the work in Appendix D precede the comprehensive planning and particularly precede the single purpose solutions. Therefore this volume, at the time of its publication, did not include data generated during the planning process. Text on techniques evolved during this period is not included either.

2. DESCRIPTION OF THE BASIN'S SURFACE WATERS

The Basin's surface waters consist of numerous streams and lakes. The Grand River flows northwesterly from its headwaters in Hillsdale County to Lansing, and thereafter, westerly through Grand Rapids to Lake Michigan. The stream bed falls 460 feet in this 260 mile course. The entire drainage are of the Basin amounts to

Table D-1

MAJOR DRAINAGE AREAS

Stream	Drainage Area at Mouth * (Square Miles)	Length of River (Miles)	Elevations Headwaters (Ft.)	Elevations Mouth (Ft.)	Average Slope (Ft./Mile)
Grand River	5,572	260	1,040	580	1.8
Rogue River	261	50	800	610	3.8
Thornapple River	875	86	900	615	3.3
Coldwater River	191	33	860	720	4.2
Mud Creek *	56	15	860	790	4.7
Flat River	556	73	900	620	3.8
Prairie Creek	103	29	800	630	5.9
Libhart Creek *	56	20	840	630	10.5
Maple River	970	71	840	630	3.0
Fish Creek	195	33	1,000	645	10.8
Stony Creek	182	30.5	830	640	6.2
Pine Creek *	83	20	750	650	5.0
Lookingglass River	312	70	900	710	2.7
Sebewa Creek	23	14	860	730	9.3
Red Cedar River	462	46	960	820	3.0
Sycamore Creek	110	22.5	1,000	820	8.0
Sloan Creek	9 **	16	920	840	5.0
Deer Creek	16 **	14	930	860	5.0
Sandstone Creek	90	23	1,000	900	4.3
Portage River	182	35	956	910	1.3
Orchard Creek	54	17	980	915	3.8

Streams underlined indicate major subbasins.

* Determined by U. S. Army, Corps of Engineers, Buffalo District
** At gage.

5,572 square miles. Seven major sub-basins comprise about 64 percent of this total Basin drainage area. They vary from 182 to 975 square miles in area. The remainder of the Basin is drained by about 30 minor tributaries whose drainage areas range from 2 to 103 square miles. Data concerning the drainage sub-basins are presented in Table D-I and on Plate D-I. There are more than 1,000 lakes quite uniformly distributed throughout the Basin. Of these, 26 have surface areas greater than 200 acres and comprise about 30 percent of the available 30,000 acres of lake surface waters within the Basin (1). Spring Lake located north of Grand Haven is the largest lake in the Basin with a surface area of 925 acres.

---

(1) The number inserted between the parentheses refers to the bibliography at the end of the paper. A particular page is referenced by a diagonal, e.g. (1/12).

SECTION II
HYDROLOGIC DATA RECORDS

3. AGENCIES GATHERING HYDROLOGIC DATA

The U. S. Geological Survey, U. S. Weather Bureau, and the Michigan Water Resources Commission are the principal collectors, recorders and publishers of streamflow data within the Grand River Basin.

4. DATA AVAILABLE

Virtually all significant surface water data collected and compiled are for streams. Initial records began in 1901 and consisted only of peak stages. The U. S. Geological Survey now operates 16 continuous-recording stream gaging stations within the Basin. Continuous-recording stream gages measure the rise and fall of surface water elevations with respect to time, thereby indicating instantaneous stream discharges. The U.S. Geological Survey stream gage stations for the Grand River at Lansing and Grand Rapids are the only two continuous-recording gages that operated within the Basin prior to 1930. In addition to the continuous-recording stream gage stations, the U. S. Geological Survey operates 21 partial-record stations within the Basin. Low and intermediate discharge measurements are utilized in the low flow analyses of water availability. Streamflow data from U. S. Geological Survey continuous-recording and partial-record stations are published for each water year (1 October thru 30 September of the following year (2)). In addition, the U. S. Geological Survey has published compilations of streamflow records of the period of record through the 1950 water year (3)), and from 1951 through the 1960 water year (4)). The U.S. Weather Bureau operates three telemark gages in the Basin and utilizes an additional three U.S. Geological Survey gages (on the Grand River at Lansing and at Grand Rapids, and on the Red Cedar River at East Lansing) to make instantaneous water surface elevations available by telephone. The U.S. Weather

TABLE D-2

U.S. GEOLOGICAL SURVEY & U.S. WEATHER BUREAU GAGES

GAGE NO.	GAGE SITE LOCATION	STREAM	DRAINAGE AREA SQ. MILES	BEGINNING DATE OF RECORD	ZERO GAGE ELEV. FT	MAXIMUM STAGE FT.	DATE	MAXIMUM DISCHARGE (CFS)	DATE	MIN. STAGE (FT.)	DATE	MINIMUM DISCHARGE (CFS)	DATE	AVERAGE DISCHARGE (CFS)
U.S.G.S. FULL RECORD STATIONS														
1090	Jackson	Grand	174	1935	900.00	13.50	25 Jun 37	1,070	25 Jun 37	8	22 Aug 36	9.2	22 Aug 36	115
1095	Munith a)	Portage	55	1945	900.00	13.00	6-7 Jun 47	800	6-7 Apr 47	7	5 Sep 46	*0	5 Sep 46	41.4
1100	Munith b)	Orchard	49	1945	900.00	14.88	5 Apr 47	1,470	5 Apr 47	7	5 Sep 46	*1.6	5 Sep 46	37.1
1110	Eaton Rapids	Grand	661	1950	852.68	8.15	4 Apr 50	3,860	4 Apr 50	0.67	20 Dec 62	14	20 Dec 62	427
1115	Dansville	Deer	16.3	1954	889.08	8.83	13 May 56	570	13 May 56	2.6	9 Dec 56	0.1	9 Dec 56	9.3
1120	Williamston	Sloan	9.3	1954	862.12	7.35	11 Jul 57	685	11 Jul 57	1.10	18 Jan 57	0.01	11 Sep 54	4.8
1125	East Lansing	Cedar	355	1931	824.39	(c)11.58	7 Apr 47	5,920	7 Apr 47	3.0	31 Jul 31	*3	31 Jul 31	202
1130	Lansing	Grand	1,230	1901	805.53	(d)15.59	7 Apr 47	16,400	26 Mar 04	0.85	9 Sep 63	2.8	9 Sep 63	820
1140	Portland	Grand	1,385	1952	705.00	11.56	31 Mar 60	9,100	13 May 56	4.0	13 Sep 63	46	13 Sep 63	788
1145	Eagle	Lookingglass	281	1944	747.09	9.9	7 Mar 56	2,860	5 Apr 47	1.0	3 Oct 53	*11	3 Oct 63	166
1150	Maple Rapids	Maple	434	1944	642.58	(e)11.22	20 Mar 48	6,500	20 Mar 48	1.74	9 Aug 63	4.6	9 Aug 63	235
1160	Ionia	Grand	2,840	1951	615.38	23.43	1 Apr 60	21,500	1 Apr 60	6.20	8 Sep 54	105	8 Sep 54	1,654
1165	Smyrna	Flat	528	1950	729.53	6.81	1 Apr 60	2,500	4 Apr 59	2.3	9 Sep 53	7.4	9 Sep 53	394
1170	Nashville	Quaker	7.6	1954	821.89	5.47	4 Oct 54	294	4 Oct 54	1.5	15 Jul 59	1.0	15 Jul 59	5.3
1175	Hastings	Thornapple	385	1944	786.71	10.20	7 Apr 47	6,810	7 Apr 47	2.73	12 Jul 63	36	12 Jul 63	289
1180	Caledonia	Thornapple	773	1951	676.31	(f)10.79	10 May 56	6,290	10 May 56	MINIMUM NOT DETERMINED				494
1185	Rockford	Rogue	234	1952	625.20	8.59	31 Mar 60	2,640	31 Mar 60	3.52	22 Jan 61	30	5 Oct 52	207
1190	Grand Rapids	Grand	4,900	1901	585.70	(g)19.50	28 Mar 04	54,000	28 Mar 04	2.25	17 Aug 36	341	17 Aug 36	3,417

U.S.G.S. LOW FLOW - CREST STAGE PARTIAL RECORD STATIONS

1184	Sparta	Rogue	155	1963

U.S.G.S. LOW FLOW PARTIAL RECORD STATIONS

1089	Vandercook	Grand	41.0	1963
1106	Henrietta	Batteese	23.8	1963
1107	Tompkins Center	Sandstone	91.2	1955
1108	Eaton Rapids	Spring	57.0	1960
1112	Fowlerville	Cedar	71.2	1963
1129	Lansing	Sycamore	96.2	1963
1142	Lainsburg	Lookingglass	88.0	1963
1146	Elsie	Maple	205.0	1963
1149	Perrington	Pine	63.0	1955
1151	Maple Rapids	Hayworth	90.0	1960
1153	Crystal	Fish	92.8	1963
1156	Hubbardston	Fish	157	1963
1158	Pewamo	Stony	175	1963
1159	Ionia	Prairie	89.6	1955
1162	Gowen	Flat	173	1963
1162.5	Greenville	Black	98.8	1963
1163	Fenwick	Dickerson	51.7	1963
1168	Vermontville	Thornapple	160	1955
1179	Freeport	Coldwater	83.5	1963
1179.5	Middleville	Coldwater	185	1963

U.S. WEATHER BUREAU STATIONS

GAGE NO.	GAGE SITE LOCATION	STREAM	DRAINAGE AREA SQ. MILES	BEGINNING RECORD DATE	ZERO GAGE ELEV.	MAX. RECORDED STAGES: STAGE FT.	MAX. RECORDED STAGES: DATE
1	Grand Rapids	Grand	4,900	1901	585.70	23.2	27 Mar 04
2	Comstock Park	Grand	-	1965	599.85	-	
3	Lowell	Grand	3,640	1904	611.58	22.1	26 Mar 04
4	Ionia	Grand	2,840	1904	615.38	27.6	27 Mar 04
5	Portland	Grand	1,390	1904	698.63	15.2	15 Mar 20
6	Grand Ledge	Grand	1,280	1904	782.85	14.0	27 Mar 04
7	Lansing	Grand	1,230	1904	805.53	(i)16.9	6 Apr 47
8	East Lansing	Red Cedar	355		824.39	(h)12.3	7 Apr 47
9	Williamston	Red Cedar	250	1925	850.84	12.0	7 Apr 47
10	Dimondale	Grand	725	1919	836.37	8.0	6 Apr 47
11	Eaton Rapids	Grand	584	1904	859.15	9.1	6 Apr 47

*Daily average

(a) Gage terminated

(b) Gage terminated

(c) Stage of 13.4 reported in March 1904 - 8,000 c.f.s.

(d) Stage of 18.6 reported in March 1904 at different datum 24,500 c.f.s.

(e) Stage of 13.8 reported in March 1904

(f) Stage of 14.4 reported in April 1947

(g) Site located 500 feet downstream from present location at datum 588.7

(h) Stage of 13.9 reported in March 1904

(i) Stage of 19.4 reported in March 1904

Note: Supplemental Data Found in Reference No. 6

Table D-3

CREST STAGE GAGES

Ident. No. (1)	Stream	Location	Zero gage Ft.
14A-1	Grand River	State Rd. Bridge	
14A-2	Grand River	M-100 Bridge - Grand Ledge	
14A-3	Grand River	Delta Mills Bridge	*
14A-4	Grand River	North Waverly Rd. Bridge	805.50
14A-5	Grand River	Mfg. Beltline RR.	812.14
14A-6	Grand River	Lansing Dam - Tailwater	811.79
14A-7	Grand River	Lansing Dam - Headwater	817.98
14A-8	Grand River	Washington Ave. - Lansing	821.19
14A-9	Grand River	Moores Dam - Tailwater	810.44
14A-10	Grand River	Moores Dam - Headwater	834.70
14A-11	Grand River	South Waverly Rd. Bridge	835.22
14A-12	Grand River	East Galway Circle Dr. Bridge	
14A-13	Grand River	Dimondale Dam - Tailwater	*
14A-14	Grand River	Dimondale Dam - Headwater	
14A-15	Grand River	M-99 Bridge	
14A-16	Grand River	Columbia Rd. Bridge	851.22
14A-17	Grand River	Bunker Hgwy. Bridge	
14A-18	Grand River	Eaton Rapids Sewage Trtmt. Plt.	
14A-19	Grand River	State St. Bridge - Eaton Rapids	
14A-20	Grand River	Main St. Bridge - Eaton Rapids	
14A-21	Grand River	Smithville Dam - Tailwater	
14A-22	Grand River	Smithville Dam - Headwater	
14A-23	Grand River	Waverly Rd. Bridge - Near Eaton Rapids	
14A-24	Grand River	Kinneville Rd. Bridge	883.34
14A-25	Grand River	Onondaga Rd. Bridge	884.28
14B-1	Red Cedar River	Pennsylvania Ave. Bridge	819.01
14B-2	Red Cedar River	C & O RR. Bridge	821.92
14B-3	Red Cedar River	East Kalamazoo St. Bridge	822.67
14B-4	Red Cedar River	Footbridge - MSU Campus	826.74
14B-5	Red Cedar River	Near Grand River Ave. Bridge	832.32
14B-6	Red Cedar River	Okemos Rd. Bridge	832.00
14B-7	Red Cedar River	Dobie Rd. Bridge	835.95
14B-8	Red Cedar River	M-43 Bridge	842.71
14B-9	Red Cedar River	Zimmer Rd. Bridge	850.65
14B-10	Red Cedar River	Williamston Dam - Tailwater	855.07
14B-11	Red Cedar River	Williamston Dam - Headwater	861.88
14B-12	Red Cedar River	Diety Rd. Bridge	862.35
14B-13	Red Cedar River	Grammer Rd. Bridge	870.77
14C-1	Sycamore Creek	Mt. Hope Ave. Bridge	820.95
14C-2	Sycamore Creek	Aurelieus Rd. Bridge	830.64
14C-3	Sycamore Creek	College Road	840.18
14C-4	Sycamore Creek	Holt Rd. Bridge	*
14C-5	Sycamore Creek	Harper Rd. Bridge	860.43
14C-6	Sycamore Creek	State St. Bridge - Mason	879.02
14C-7	Sycamore Creek	West Elm Bridge - Mason	881.52
14C-8	Mud Creek	Harper Rd. Bridge	862.57
14C-9	Mud Creek	Columbia Rd. Bridge	900.52
14D-1	Lookingglass River	Howe Rd. Bridge	*
14D-2	Lookingglass River	Talliman Rd. Bridge	
14D-3	Lookingglass River	Wacousta Rd. Bridge	
14D-4	Lookingglass River	Habison Rd. Bridge	
14D-5	Lookingglass River	Lowell Rd. Bridge	
14D-6	Lookingglass River	Airport Rd. Bridge	
14D-7	Lookingglass River	DeWitt Rd. Bridge	
14D-8	Lookingglass River	Williams Rd. Bridge	
14D-9	Lookingglass River	Chandler Rd. Bridge	
14D-10	Lookingglass River	Babcock Rd. Bridge	
14D-11	Lookingglass River	Hollister Rd. Bridges	

(1) Michigan Water Resources Commission Identification Number.
* Gage not installed

Bureau also operates 11 non-recording stage gages within the Basin for flood forecasting. Flood stage data and records of daily stages for the U. S. Weather Bureau gages at Lansing and Grand Rapids are published annually (5). Records of daily stages of the remaining nine stations may be obtained from the U. S. Weather Bureau Section Center in East Lansing. U. S. Weather Bureau and U. S. Geological Survey stream gage data are presented in Table D-2; locations of the gages are on Plate D-1. The Michigan Water Resources Commission, in cooperation with certain local municipalities, has recently installed, or is in the process of installing, 58 crest stage gages in Ingham, Eaton and Clinton Counties, near Lansing. The primary purpose of these gages is to provide highwater marks for establishing flood profiles. These gages are shown on Plate D-2, and noted in Table D-3. Their records may be obtained from the Michigan Water Resources Commission in Lansing.

5. FUTURE REQUIREMENTS

Any future water resource projects in the Basin should include extension of the existing stream gaging program. New telemark stations installed at strategic locations will be needed to provide immediate and concise data for the operation of the reservoir system, as well as to provide information on current stream conditions throughout the Basin. The number and location of future gaging stations will be developed as a part of the operating procedures of the plan of development and will be discussed in greater detail as the project is formulated.

SECTION III
STREAMFLOW

6. DEFINITIONS

Formulation of the optimum plan for water resource development requires an inventory of the streamflow; where it is located, how much there is, its period of occurrence, and what is required for its control to meet a variety of needs. Streamflow is the quantity of water that passes a given point on the stream in a specified period of time.

Streamflow is expressed in either cubic feet per second (C.F.S) or cubic feet per second per square mile of drainage area (C.F.S.M.). It is composed almost entirely of runoff water. Runoff water or runoff is that part of the total precipitation that finds its way to the surface streams (7). Precipitation produces streamflow from combinations of groundwater, subsurface, and surface runoffs. Each form of runoff is significant in the utilization of water resources. Surface runoff is that portion of precipitation that does not penetrate the surface and drains directly overland to the stream. Subsurface runoff is that portion of precipitation that penetrates the surface and moves laterally through the upper soil layers to the stream. Groundwater runoff is that portion of precipitation that penetrates the surface, infiltrates to the water table, and is discharged into the stream. Flood flows normally result from surface runoff. Normal flows are usually a combination of subsurface and groundwater runoffs. Low flows consist of virtually only groundwater runoff.

7. MAXIMUM STREAMFLOW

The maximum recorded discharge for the Grand River at Grand Rapids is 54,000 c.f.s. in March 1904. The maximum recorded peak runoff for each U. S. Geological Survey continuous recording streamflow station within the Basin is presented in Table D-2. Recorded maximum peak runoff rates vary considerably within the Basin. Recorded peak runoff rates vary from 14 C.F.S.M. to over 70 C.F.S.M. for drainage areas under 60 square miles. Recorded maximum peak runoff rates vary from 5 C.F.S.M. to 20 C.F.S.M. for the larger watersheds. Maximum runoff rates have usually occurred during the late winter and early spring months of March through April when moderate rainfall amounts have accompanied variable snowmelt amounts. Detailed information concerning maximum flows are presented in paragraph 13, Analysis of Flood Periods, of this Appendix.

8. NORMAL STREAMFLOW

There are several methods and ways in which normal flows are determined and expressed. Mean annual flows are the mathematical average of the monthly mean flows which in turn are the mean of the daily average flows. Extreme values of either high or low flows greatly affect the mathematical average flow. Recurrence frequencies are not normally associated with average flows. Mean annual and mean monthly flow statistics provide an indication of the amount, distribution, and variation of Basin runoff. Mean annual flow for each U.S.G.S. continuous recording station is presented in Table D-2. Selection of the year 1945 as a base year provides a comparable period of record from which to inspect variations in monthly streamflows throughout the Basin. Mean monthly flows for all U. S. Geological Survey continuous recording stations are presented in Table D-4. Examination of the average annual and monthly runoff rates reveals that the Rogue, Thornapple, and Flat basins have the highest water yield streams in the Basin. (The mean flow rate within the Basin is about 0.7 C.F.S.M., with a maximum average annual flow rate of 0.8 C.F.S.M., and a minimum average annual flow rate of 0.5 C.F.S.M.) Estimates of the variations in average Basin runoff are made from streamflow records for the Grand River at Lansing and Grand Rapids. These records show that there are 18 years when below average annual flows occurred mutually at the two stations. Individually, these records show 22 years of below average annual flows at Lansing, and 24 years of below average annual flows at Grand Rapids. In contrast, records at Lansing show 14 years of above average annual flows, while Grand Rapids records show 15 years of above average annual flows, with 12 of these years common to both stations. The longest period of continuous below average annual flows common to both stations is 5 years, while the minimum common period of continuous below average annual flows is one year. The longest common period of continuous above average annual flows is 3 years, while the minimum common period of above average annual flows is one year. The Basin average monthly flow rates range from a high of 1.5 C.F.S.M. in March to 0.3 C.F.S.M. in August.

Individual station monthly maximum rates vary from 1.3 C.F.S.M. to 1.9 C.F.S.M., while monthly minimum rates vary from 0.1 C.F.S.M. to 0.5 C.F.S.M. Normal flow is the flow that is equaled or exceeded 50 percent of the time. This statistic provides an estimate of the yield potential of the various streams in the Basin. The flow rate that is equaled or exceeded 50 percent of the time in the Basin is about 0.5 C.F.S.M. Flow rates that are equaled or exceeded 50 percent of the time for individual stations vary throughout the Basin from a maximum of 0.7 C.F.S.M. to a minimum of 0.1 C.F.S.M.

9. MINIMUM STREAMFLOW

Recorded minimum discharges for the Grand River at Lansing and Grand Rapids are 3 C.F.S. * and 341 C.F.S., respectively. The recorded minimum discharges for each U. S. Geological Survey continuous recording station within the Basin are presented in Table D-2. Recorded minimum daily runoff rates vary from 0.001 C.F.S.M. to 0.131 C.F.S.M. for streams with less than 60 square miles of drainage area. Recorded minimum daily runoff rates vary from 0.002 C.F.S.M. to 0.116 C.F.S.M. for streams that drain over 60 square miles. Minimum recorded streamflows have usually occurred during the warm summer months of July through September when extreme durations of insignificant precipitation, that have extended over two week periods, have occurred. Most minimum discharges recorded within the Basin occurred during the lowest period of below average annual precipitations recorded since the stream gage station began collecting streamflow data. Low flows are discussed in greater detail in paragraph 14, Analysis of Low Flow Periods, of this Appendix.

10. YIELDS, DISTRIBUTION, AND VARIATION IN STREAMFLOW

A low flow series analysis of streamflow data provides a measure of streamflow yields, distributions and variations. A flow-duration analysis is used to measure the yield potential, distribution, and variation in stream flows throughout the Basin. This analysis provides

*Resulted from regulation of stream in Lansing

TABLE D-4

COMPARATIVE MEAN MONTHLY DISCHARGE RATES
(1945-1963)

Site Location Near	Stream	Records from year	Jan. CFS	Feb. CFS	Mar. CFS	Apr. CFS	May CFS	Jun. CFS	Jul. CFS	Aug. CFS	Sep. CFS	Oct. CFS	Nov. CFS	Dec. CFS
Jackson	Grand River	1945	116	132	215	231	172	107	72	51	50	70	86	97
Munith	Portage River	1945	40	45	98	110	77	44	16	7.2	11	23	29	32
Munith	Orchard Creek	1945	40	45	83	89	62	43	13	7.5	13	15	18	27
Eaton Rapids	Grand River	1950	453	506	895	834	618	347	221	145	131	261	346	374
Dansville	Deer Creek	1954	6.6	8.8	27	18	13	8.5	6.5	2.6	1.9	6.1	6.6	6.9
Williamston	Sloan Creek	1954	2.7	4.0	16	9.5	8.6	3.1	3.5	1.5	0.8	2.8	2.6	3.1
East Lansing	Cedar River	1945	209	253	547	483	361	168	93	54	58	108	120	154
Lansing	Grand River	1945	793	911	1848	1796	1304	716	393	244	251	424	518	619
Portland	Grand River	1952	461	781	1906	1561	1306	670	453	298	256	460	571	592
Eagle	Look[illegible]glass R.	1945	161	186	430	376	276	126	53	45	57	73	97	118
Maple Rapids	Maple River	1945	227	225	686	562	390	164	86.9	52.8	70.1	81.5	120	158
Ionia	Grand River	1951	1559	1665	4054	3469	2735	1208	876	591	493	823	1200	1205
Smyrna	Flat River	1951	357	388	626	682	698	321	261	250	248	314	385	364
Nashville	Quaker Brook	1954	4.7	5.8	11	7.9	6.7	4.0	3.0	2.7	2.6	4.9	5.2	4.9
Hastings	Thornapple River	1945	309	308	670	586	451	236	130	99	108	166	193	227
Caledonia	Thornapple River	1951	518	508	1062	925	822	411	297	243	217	355	438	426
Rockford	Rogue River	1952	174	212	365	342	297	182	139	129	120	166	203	189
Grand Rapids	Grand River	1945	3309	3483	7315	7054	5385	2877	2111	1465	1538	1836	2370	2680

Table D-5

COMPARISON OF SUBBASIN YIELDS AND VARIATIONS IN STREAMFLOW

Subbasin	G.R. U/S Jackson	G. R. U/S E. R.	Red Cedar R.	Lookingglass R.	Comparison Rating
Grand R. U/S Jackson					
Greater Yield	-	-	-	-	5
Smaller Variation	-	-	-	-	
Grand R. U/S Eaton Rapids					
Greater Yield	Same	-	-	-	5
Smaller Variation	Same	-	-	-	
Red Cedar R. U/S E. Lansing					
Greater Yield	G. R. U/S Jackson	G. R. U/S E. R.	-	-	6
Smaller Variation	G. R. U/S Jackson	G. R. U/S E. R.	-	-	
Lookingglass R. U/S Eagle					
Greater Yield	Same	G. R. U/S E. R.	Same	-	6
Smaller Variation	G. R. U/S Jackson	G. R. U/S E. R.	Same	-	
Maple River U/S Maple Rapids					
Greater Yield	Same	G. R. U/S E. R.	Same	Same	6
Smaller Variation	G. R. U/S Jackson	G. R. U/S E. R.	Same	Lookingglass	
Thornapple R. U/S Hastings					
Greater Yield	Thorn. U/S Hast.	Thorn. U/S Hast.	Thorn. U/S Hast.	Thorn U/S Hast.	1
Smaller Variation	G. R. U/S Jackson	G. R. U/S E. R.	Thorn. U/S Hast.	Same	
Thornapple R. U/S Caledonia					
Greater Yield	Same	Same	Thorn. U/S Cald.	Thorn U/S Cald.	4
Smaller Variation	Same	Same	Thorn. U/S Cald.	Thorn U/S Cald.	
Flat R. U/S Smyrna					
Greater Yield	Flat R.	Flat R.	Flat R.	Flat R.	3
Smaller Variation	Flat R.	Flat R.	Flat R.	Flat R.	
Rogue R. U/S Rockford					
Greater Yield	Rogue R.	Rogue R.	Rogue R.	Rogue R.	2
Smaller Variation	Rogue R.	Rogue R.	Rogue R.	Rogue R.	

Subbasin	Maple R.	Thorn. U/S Hastings	Thorn. U/S Cald.	Flat R.	Comparison Rating
Grand R. U/S Jackson					
Greater Yield	-	-	-	-	5
Smaller Variation	-	-	-	-	
Grand R. U/S Eaton Rapids					
Greater Yield	-	-	-	-	5
Smaller Variation	-	-	-	-	
Red Cedar R. U/S E. Lansing					
Greater Yield	-	-	-	-	6
Smaller Variation	-	-	-	-	
Lookingglass R. U/S Eagle					
Greater Yield	-	-	-	-	6
Smaller Variation	-	-	-	-	
Maple River U/S Maple Rapids					
Greater Yield	-	-	-	-	6
Smaller Variation	-	-	-	-	
Thornapple R. U/S Hastings					
Greater Yield	Thorn. U/S Hast.	-	-	-	1
Smaller Variation	Thorn. U/S Hast.	-	-	-	
Thornapple R. U/S Caledonia					
Greater Yield	Thorn U/S Hast.	Thorn U/S Hast.	-	-	4
Smaller Variation	Thorn U/S Hast.	Thorn U/S Cald.	-	-	
Flat R. U/S Smyrna					
Greater Yield	Flat R.	Thorn. U/S Hast.	Flat R.	-	3
Smaller Variation	Flat R.	Flat R.	Flat R.	-	
Rogue R. U/S Rockford					
Greater Yield	Rogue R.	Thorn. U/S Hast.	Rogue R.	Rogue R.	2
Smaller Variation	Rogue R.	Rogue R.	Same	Rogue R.	

data, based on the period of record, as to the percent of time various rates of flow are equaled or exceeded. Flow-duration relationships for 16 U. S. Geological Survey continuous recording stations are presented on Plate D-3 through Plate D-18.* Generalized hydrologic information interpreted from these relationships consists of the yields and variations in streamflow. Location of the curve in the upper portion of the graph paper indicates a high yield stream. The steepness of the slope of this curve indicates the degree of variation in the extreme high and low flows. Comparison of these characteristics reveals those areas of greater yield potential and stability. Comparison of the flow-duration relationships developed for the major sub-basins are presented in Table D-5. Results of these comparisons reaffirm the previously mentioned estimate that the Thornapple, Rogue, and Flat rivers have the greatest yield rates in the Basin. These comparisons also indicate that these streams are also the most stable within the Basin. Low and/or high flows on these streams are experienced less often than on the other major streams in the Basin.

*Reference to Plates D-3 through D-18 includes those sheets lettered A and B for the respective plate numbers.

11. <u>EFFECTS OF EXISTING PROJECTS ON STREAMFLOWS</u>

Local interests have developed numerous projects within the Grand River Basin for water power development, flood control, water supply, navigation, and irrigation. The extent of the effects of these projects on surface waters are generally localized. Except for these localized effects, the Basin's surface waters are practically unregulated even during flood periods. Descriptions of the major projects and their effects on surface waters are presented in the following paragraphs:

a. <u>Jackson</u>. The Michigan Center Mill Pond, located upstream of Jackson, is used to control spring runoff. In the 1930's, the City of Jackson built a concrete conduit through the downtown area to contain flood flows and improve general conditions in this reach of the Grand River. These projects have only local effects on Grand River flows.

b. <u>Eaton Rapids</u>. Streamflow at Eaton Rapids is affected by three dams on the Grand River and a control structure on Spring Brook. Two of the Grand River dams are for power development. One of the dams is about 2 miles upstream from Eaton Rapids, at Smithville; the other is at Eaton Rapids. The third dam is for water supply for scenic purposes within Eaton Rapids. The control structure on Spring Brook in Eaton Rapids is for power development. The operation of these facilities has significant effects on flood and low flows at Eaton Rapids.

c. <u>Dimondale</u>. A low head dam exists at Dimondale for power production. The structure is not now maintained and has little effect on Grand River flows.

d. <u>East Lansing</u>. A dam which was constructed on the Red Cedar River at Williamston in the 1880's for the purpose of power production is now unused and has little effect on flood or low flows at East Lansing. One other dam, located on the Michigan State University campus, provides water for cooling at the University's power plant. This dam has little effect on flood or low flows.

e. Lansing. An earth dike, constructed in 1936 along the Red Cedar River, protects low lying areas from all but major floods. Drainage is provided for the diked landward area by storm water pumps, which were installed after the 1947 flood. There are two dams located on the Grand River in Lansing for power production. These dams have only local effects on Grand River flows.

f. Grand Ledge. There is a low head dam in Grand Ledge, for water supply for sanitation purposes. The dam has only a minor effect on the Grand River flows.

g. Portland. A dam for power is located on the Grand River about 4 miles downstream from Portland. The dam has only local effects on Grand River flows.

h. Lyons. A low head dam for power is located on the Grand River at Lyons. It has only minor effects on Grand River flows. The largest structure on the Grand River is at Webber about six miles upstream from Lyons. The operation of this dam has significant effects on Grand River flows at Lyons.

i. Lowell. A dam for power is located in Lowell on the Flat River just upstream from its confluence with the Grand River. The dam has significant effects on Flat River flows in Lowell. The significance of these effects is especially dependent on the coincidental Grand River flows.

j. Dams on Thornapple River. Several dams exist on the Thornapple River for power development. There is no known operating plan for floods for this system; thus, it is assumed that the pools are maintained as high as possible, and therefore have little effect on flood flows. The system has significant effects on normal and low flows from the Thornapple.

k. Grand Rapids. A dam for power is located in Grand Rapids on the Grand River and has only local effect on Grand River flows. A flood protection system, constructed after the 1904 and 1905 floods in Grand Rapids, consists of floodwalls and embankments on both banks of the river, and the diversion of sanitary and combined sewers to the Sewage Treatment Plant. All flood protection facilities are above the record 1904 high water stages. This system has significant effects on Grand River flows in the Grand Rapids area.

l. Agricultural Drains. Flows increase in the major streams as poorly drained agricultural areas acquire improved drainage facilities. No significant effects in the runoff characteristics of the major streams in the Basin are evident as a result of the various improvements made in the agricultural areas in recent years.

m. Navigation Projects. A navigation project exists from Lake Michigan up the Grand River about 18 miles, and maintains a project depth of 8 feet to Bass Island, a distance of 14-1/2 miles. This project's backwater effects do not extend up to major drainage areas located upstream of Grandville.

n. Water Supply Facilities. The City of Rockford obtains its water supply from the Rogue River. With the exception of Grand Rapids and Grand Haven, other water supplies in the Basin are obtained from groundwater aquifers. Grand Rapids and Grand Haven obtain their water from Lake Michigan. Any depletion of streamflow by withdrawal from these aquifers is not considered significant under present conditions. However, it is estimated that Grand River flows at Jackson and Lansing would be depleted by 15 c.f.s. and 54 c.f.s., respectively, by the projected future use of present groundwater resources.

12. STREAMFLOW ROUTING

Runoff from a drainage basin is determined by climatic and physiographic factors. The major climatic factors are precipitation, interception (vegetation species, season of the year, size of storm), evaporation, and transpiration. Major physiographic factors are basin characteristics (size, shape, slope, land use and cover, soil type) and channel characteristics (size, slope, length, roughness). Streamflow routing is the procedure whereby the time and magnitude of flows of a stream are determined for a particular location from the known or estimated climatic and physiographic conditions at one or more points upstream (9/1). Reservoir routing is the procedure whereby the modifying effects on inflows by a reservoir are determined from the known or estimated hydrographs upstream and downstream of the reservoir.

Routings utilized in this study are described in detail in Grand River Basin Technical Paper No. 1 - Streamflow and Reservoir Routing (10). Methods used in this study are summarized in the following paragraphs.

a. Routing of natural streamflow and reservoir releases. Three factors have significant effects on natural streamflow and reservoir releases, namely, hydraulic structures, valley storage, and conveyance factors. In this study, hydraulic structures are limited to those that have the ability to significantly influence the stream regimen (11). Valley storage is the combined channel storage and out of bank storage, which includes the natural flood plain of the channel (12/5). The conveyance factor is a measure of the volume change that occurs when water flows from an upstream point, to a downstream point, disregarding local inflow. This factor is a function of evaporation losses, transpiration losses, irrigational losses, seepage losses, and the addition of rainfall and groundwater. The effect that these components have on flows, is dependent on several factors of which the magnitude of flow is the most important. Two periods of stream routing are significant, namely, flood periods and low flow periods.

(1) Routing of flood flows. The causes differ from area to area within a Basin. The variations in rainfall, moisture conditions, storm orientation, and runoff characteristics of the numerous basin sub-areas, necessitate a somewhat detailed analysis of the Basin's flood characteristics in order to route flood flows.

(a) Routing of unregulated flows during flood periods.

1. Explanation of the progressive average lag method. The progressive average lag method (9) of flood routing provides adequate initial flood flow data. This procedure requires a minimum of input data and provides reasonable results. Input data consists of the known or calculated flood hydrograph at one or more points upstream and an estimate of the travel time to the downstream point of interest. The known hydrographs are recorded flood hydrographs. Calculated hydrographs are developed from application of rainfall excess amounts to unit hydrographs. The accuracy is checked by routing runoff from a known

storm and reproducing a recorded hydrograph. This method approximates the modifying effects of downstream reaches on flood hydrographs by averaging successive flows. The number of flows averaged is determined by trial and error until a satisfactory agreement is obtained between the computed and recorded hydrographs. The inflow durations were averaged and were found to be normally from three-quarters to twice the travel time.

<u>2</u>. <u>Assumptions</u>.

<u>a</u>. Most of the existing dams in the Basin are for generation of electricity or for cooling. It is assumed for the routing that the pool elevations for these dams are at all times maintained as high as possible, so their effects on flood flows are minor.

<u>b</u>. The calculated hydrograph resulting at the downstream point shows the increased flow. This includes the effect of the valley storage in the reach.

<u>c</u>. Conveyance losses are not considered important. Comparison of these losses to flood flows indicated that these losses are insignificant.

<u>d</u>. The relationship between unrouted and routed discharges applies to all equal time periods.

(b) <u>Routing of reservoir releases during flood periods</u>.

<u>1</u>. <u>Explanation of method</u>. Reservoir releases are constantly made during flood test periods. The data required for these routings are the amounts of reservoir releases and the travel times from the reservoir to the downstream point of interest.

<u>2</u>. <u>Assumptions</u>.

<u>a</u>. Existing structures on the stream have no significant effect on the water flow. Since nearly all dams on the stream in the Basin are for power development or for cooling purposes their pool elevations are assumed to be as high as possible, so their effects on flow are minor.

b. Valley storage effects on streamflow are insignificant. The valley storage volume is small in comparison to the large volumes of water released during floods.

c. Conveyance losses are insignificant. Comparison of conveyance factors to flood release rates indicated minor effects on reservoir releases.

(2) Routing of normal and low streamflows. Components of normal and subnormal climatic periods are fairly uniform throughout the Grand River Basin (13). General descriptions given for the Basin (8) indicate fairly uniform physiographic characteristics throughout. Because the factors that produce normal and low flows do not vary greatly in the Basin, a detailed analysis is not necessary in determining expected normal and low flows from the several areas. The effects of the existing structures on normal and low flows are unimportant. Most of the dams on the streams are small and are for generation of electricity or for cooling. It is assumed that the pool elevations would be maintained as high as possible at all times, and would thus have little effect on streamflows. The effects of valley storage and conveyance factors could be significant on streamflows, especially during low flow periods. These effects are evaluated.

(a) Routing of unregulated streamflows during normal and low flow periods.

1. Explanation of method. Conveyance losses are considered significant during normal and low flows. Their effect on streamflow is considered by the following procedure. Conveyance losses in a stream reach are equal to the summation of losses due to the irrigation, seepage, groundwater and evapotranspiration, less gains due to rainfall.

2. Assumptions.

a. Channel cross section is uniform throughout its length.

b. Average monthly rainfall and evaporation amounts occur for the period tested.

c. Irrigational demands estimated by the Soil Conservation Service occur for the period tested.

d. Transpiration, seepage and groundwater factors estimated by the Corps of Engineers occur for the period tested.

(b) Routing of reservoir releases during normal and low flow periods.

1. Explanation of method. Valley storage and conveyance losses are considered significant on flow during reservoir releases. Conveyance losses are calculated by the following procedure. The additional reservoir release necessary to compensate for conveyance losses in a reach is equal to the summation of losses due to irrigation withdrawals, seepage into groundwater, and evapotranspiration, less gains due to rainfall. This estimates the additional water releases necessary for downstream needs; it also measures the effect that these volumes would have on the reservoir water levels.

2. Assumptions.

a. Channel cross section is uniform throughout its length from the reservoir to the downstream point of interest.

b. Average monthly rainfall and evaporation amounts occur for the period tested and are uniformly distributed along the stream.

c. Irrigation demands estimated by the Soil Conservation Service are made for the period tested.

d. Transpiration, seepage and groundwater factors estimated by the Corps of Engineers apply during the period tested.

b. Routing of flows through a reservoir system. Routing of flows through a reservoir system depends on many factors, of which the magnitude of flow, size of reservoirs, downstream channel capacities, the ability of the reservoirs to make releases, the number of reservoirs in the Basin system, and the desired flow at a downstream point of interest are most important. The routing procedure selected is governed to a great extent

on the type of data available for each of these factors. The routing procedure selected also depends on the purpose for which the routings are to be performed. Two periods of routings are important, namely, flood periods and low flow periods.

(1) Flood routing through a reservoir system.

(a) Flood routing through a single reservoir.

1. Graphical method.

a. Explanation of method. This method results in an approximate outflow hydrograph from a reservoir, based on the storage-capacity and outlet facilities of the reservoir. Data required consist of an outflow hydrograph at the reservoir, the uncontrolled area hydrograph downstream of the reservoir, the storage-capacity of the reservoir and travel times from the reservoirs to the downstream areas. By this method, a series of non-damaging flows is calculated with an uncontrolled area of flow downstream of the reservoir. When the total storage required exceeds the storage available at a site, outflows are increased uniformly until the actual storage available is not exceeded.

b. Assumptions.

1. Storage capacities adequate for the selected floods are available at each reservoir.

2. Outlet facilities are capable of discharging computed releases.

(b) Routing of flood flows through a reservor system.

1. Explanation of method. When the object of the operating plan of a reservoir system is to limit flood flows to non-damaging rates at selected locations, reservoir releases are set at these non-damaging rates. Routings of test flood flows through the reservoir system are then made in an attempt to maintain these non-damaging rates as long as conditions and performance of the reservoir system do not become objectionable. When conditions and characteristics of the system and Basin become objectionable, releases are made that insure the safety of the reservoir system from failure. Data required in this routing procedure consist of inflow hydrographs at the reservoirs, the uncontrolled area hydrographs at the selected index points, the storage

volumes available in the reservoirs, the maximum allowable discharge at an index point, stream travel times between reservoirs and index point, and channel capacities downstream of the reservoirs. The premises upon which this method is primarily based can be stated as follows. The downstream point of interest determines the allowable storage in downstream reservoirs and limits the allowable release rates from the upstream reservoirs; the releases from upstream reservoirs are also determined from reservoir inflows and storages available. An interior reservoir is any reservoir that has a reservoir located upstream from it. An exterior reservoir is one that does not have a reservoir located upstream from it.

2. Assumptions.

a. Dam outlets are capable of making computed releases.

b. Channel flow is not significantly affected by existing structures, conveyance losses, and valley storage.

c. Reservoir storages are not significantly affected by evapotranspiration or direct rainfall.

d. Reservoir release travel times are similar to natural travel times.

e. Reservoir inflow and releases remain constant for a time interval equal to the time period of the hydrograph ordinates.

f. The total reservoir flood control storage is available when flood routing is initiated.

(2) Routing of normal and low flows through a reservoir system.

(a) Explanation of method. During routings of normal and low flows through a reservoir system, the amount of flow under study is maintained at selected downstream locations as long as conditions and characteristics of the Basin permit. When unsuitable conditions develop releases are made from other reservoirs to correct anything unsatisfactory at the downstream locations of interest. Should

the Basin and the reservoir system be unable to meet these demands, it is noted as a period of unsatisfactory performance of the reservoir system. Data required in this routing procedure consist of inflow hydrographs at the reservoirs, the uncontrolled area hydrographs at index locations, the storages available in the reservoirs, the minimum allowable discharges at index locations, rainfall and evapotranspiration, valley storage and conveyance losses. The premise upon which this method is based can be stated as follows: The downstream location of interest determines the minimum allowable releases from those reservoirs immediately upstream; the available storage in interior reservoirs limits the maximum allowable release rates from the upstream reservoirs; and the releases from the exterior reservoirs are determined from the maximum allowable releases to the downstream reservoirs, reservoir inflows, and storages available.

(b) Assumptions

1. When data is not available, the reservoir is represented by a right triangular prism.

2. Average monthly rainfall and evaporation occur for the period tested and are uniformly distributed over the reservoir.

3. Transpiration factors estimated by the Corps of Engineers apply for the period tested.

4. Demand rates estimated by the Federal Water Pollution Control Administration apply during the period tested.

5. Physical data on reservoirs compiled by the Corps of Engineers (13) are applicable.

6. Seepage losses at the reservoir are negligible.

13. ANALYSIS OF FLOOD PERIODS

a. General. Floods in the Grand River basin are a result of either frontal or convective air mass types of rain storms. Floods produced from the frontal type usually occur in the early spring months of March and April when the ground surface is nearly saturated and/or a snow cover exists. The 1904, 1947 and 1948 floods resulted from the occurrence of this type of storm. Floods produced from convective air

TABLE D-6

DATA FOR GRAND RIVER MAJOR FLOODS

	U. S. Geological Survey Gage Location		
	E. Lansing (Red Cedar River)	Lansing (Grand River)	Grand Rapids (Grand River)
(1) Flood Stage, feet	832.0	819.0	603.7
Related Discharge, cfs.	2,500	10,000	27,000
1904 Flood			
Stage - Ft.	837.8	825.2	610.0
Discharge - C.F.S.	8,000	24,500	54,000
Volume - Inches	3,53	3.50	2.04
(2) Duration - Days	6	6	10
1905 Flood			
Stage - Ft.	834.7	820.3	609.4
Discharge - C.F.S.	4,900	12,800	50,200
Volume - Inches	1.83	1.45	2.04
Duration - Days	4	4	7
1947 Flood			
Stage - Ft.	835.9	822.5	606.8
Discharge - C.F.S.	4,900	16,400	38,600
Volume - Inches	1.54	1.38	1.33
Duration - Days	4	3	5
1948 Flood			
Stage - Ft.	834.9	820.0	607.6
Discharge - C.F.S.	4,960	12,000	42,200
Volume - Inches	1.32	1.08	1.46
Duration - Days	3	1	5

(1) Also known as "Zero Damage Elevation and Discharge"
(2) Length of time above flood stage

mass storms usually occur in the summer months as a result of very high rainfall amounts over relatively short periods of time. With the exception of the June 1905 flood, this type of storm is localized so that only a relatively small area is subject to flooding. Past records indicate that the occurrence of severe Basin-wide flooding from frontal type storms is more likely than the occurrence of flooding from convective air mass storms. This is evident from U. S. Weather Bureau and U. S. Geological Survey records which indicate that with the exception of the June 1905 storm, maximum recorded precipitation rates and amounts within the Basin are not associated with unusually high stream discharges. Important parameters of floods are the flood stage, the maximum discharge, the volume of flow, and the duration of flood stages. Pertinent flood data for the floods of 1904, 1905, 1947 and 1948 at East Lansing, Lansing, and Grand Rapids are described in the following paragraphs of this Appendix, and presented in Table D-6. Flood profiles for the floods of 1904, 1905, 1947 and 1948 on the Grand and Red Cedar rivers are shown on Plate D-19.

b. Notable floods of record.

(1) Flood of March 1904. The flood of March 1904 is the greatest flood of record in the entire Basin. About 1 inch of precipitation from a frontal storm moving across the Great Lakes fell on the Basin. This rainfall accompanied by rapid melt of excessive snow cover in the headwater areas of the Red Cedar River basin produced the flood conditions. Record flood stages and discharges were measured and recorded at nearly all major cities located downstream of Lansing. The maximum discharge for this flood was 54,000 c.f.s. for the Grand River at Grand Rapids. A runoff volume of 3.5 inches was determined at Lansing and 2.0 inches at Grand Rapids. The durations of river stages above flood stage were about 6 days at Lansing and about 10 days at Grand Rapids.

(2) Flood of June 1905. The flood of June 1905 is the second greatest flood of record in the entire Basin. High flood stages were recorded at most major cities as a result of runoff from intense wide-spread thunderstorm activity. A record Basin-wide average precipitation amount of 4.6 inches was determined for the Basin. The discharge for the Grand River at Grand Rapids of 50,200 c.f.s. nearly equaled the maximum discharge of 54,000 c.f.s. recorded in March 1904. Runoff volumes of 1.5 inches and 2.0 inches were determined for the Grand River at Lansing and Grand Rapids, respectively. The duration of river stages above flood stage was 3 days at Lansing, and 7 days at Grand Rapids.

(3) Flood of April 1947. During the middle of March 1947, snow fell to an average depth of 9 inches over the entire Basin. The temperatures remained at freezing during the remainder of the month. A frontal storm moved into the Basin the first week in April. Rainfall amounts were moderate to heavy and were centered in the headwater area near Jackson. Temperatures were in the 60's. As a result of the rainfall and accompanying snowmelt, serious floods occurred in the Basin. A maximum discharge of 38,600 c.f.s. was recorded for the Grand River at Grand Rapids. Runoff volumes ranged from 1.4 inches at Lansing to 1.3 inches at Grand Rapids. Flood durations above flood stages varied from 3 days at Lansing to 5 days at Grand Rapids.

(4) Flood of March 1948. The last major flood experienced in the Basin resulted from a combination of snowmelt and moderate rainfall centered near Lansing. About 10 inches of snow fell on the Basin two weeks prior to rainfall. Most of the snow remained on the ground as temperatures stayed below freezing. Then an average precipitation of 2.4 inches fell on the entire Basin while temperatures rose to the 60's. It is interesting to note that Grand River flood stages reached from this flood were greater downstream of Portland than the stages of the April 1947 flood, while upstream of Portland, Grand River stages were less for the March 1948 flood than for the April 1947 flood. The greater discharges for the Grand River downstream of Portland during the March

1948 flood are explained by the greater rainfall amounts experienced downstream of Lansing during the March 1948 storm compared to the April 1947 storm. It is also noted that the 42,200 c.f.s. maximum at Grand Rapids for the 1948 flood occurred about 18 hours earlier from the midpoint of rainfall excess than the 1947 flood maximum. This indicates that the critical storm pattern for the Grand Rapids area was centered downstream of Lansing. Runoff volumes varied from 1.1 inches at Lansing to 1.5 inches at Grand Rapids. Flood stages were exceeded about 1 day at Lansing and about 5 days at Grand Rapids.

c. Routing of flood flows. The April 1947 and March 1948 floods were analyzed in detail by flood routing studies. Flood hydrographs recorded at various locations within the Basin were satisfactorily reproduced using the progressive-average-lag method of flood routing. A description of these two flood routings are presented in the following paragraphs.

(1) April 1947. Observed U. S. Geological Survey hydrographs were available for the Grand River at Jackson, Lansing and Grand Rapids, the Red Cedar River at East Lansing, the Portage River near Munith, Orchard Creek near Munith, the Lookingglass River at Eagle, the Maple River at Maple Rapids, and the Thornapple River at Hastings. In addition, the U. S. Weather Bureau recorded flood stages on the Grand River at Eaton Rapids, Dimondale, Grand Ledge, Lansing, Portland, Ionia, Lowell, and Grand Rapids, and on the Red Cedar River at Williamston and East Lansing. Rainfall amounts for the sub-basins were estimated from the isohyetal map of the April 1947 storm, shown in Appendix C - Climate - Plate C-12. Excess rainfalls applied to sub-basin unitgraphs were estimated from excess runoffs determined from observed hydrographs. Routed and observed hydrographs for the Grand River at Lansing and Grand Rapids are shown on Plates D-20 and D-21, respectively.

(2) March 1948. Observed U. S. Geological Survey hydrographs were available for the Grand River at Jackson, Lansing, and Grand Rapids, the Red Cedar River at East Lansing, the Portage River and Orchard Creek near Munith, the Lookingglass River at Eagle, the Maple River at Maple Rapids,

and the Thornapple River at Hastings. In addition, the U. S. Weather Bureau recorded flood stages on the Grand River at Eaton Rapids, Dimondale, Grand Ledge, Portland, Ionia, Lowell and Grand Rapids, and on the Red Cedar River at Williamston and East Lansing. Rainfall amounts were estimated from the isohyetal map for the March 1948 storm shown in Appendix C - Climate - Plate C-13. Excess rainfalls applied to sub-basin unitgraphs were estimated from runoffs determined from observed hydrographs. Routed and observed hydrographs for the Grand River at Grand Rapids are shown on Plate D-22.

d. Basin flood characteristics. Investigation of flood and storm phenomena reveals four significant factors concerning the Basin's flood characteristics, namely, seasonal and/or antecedent conditions, storm orientation, rainfall intensity and rainfall duration. The flood potential of the Basin is dependent on the occurrence of these factors. Another important consideration of Basin flood characteristics is the possibility of a second storm occurring over the Basin immediately after the occurrence of a flood producing storm. These factors are described in detail in the following paragraphs.

(1) Antecedent conditions. Basin-wide floods have usually occurred during the early spring months of March and April. During these months, extensive snowmelt with moderate rainfall produce high river stages as a result of runoff from frozen ground with little vegetative cover. Extensive snowmelt prior to storms during this period has comprised from 25 percent to 40 percent of the maximum flows on the Grand River. Temperatures are also significant in determining the amount of flooding during these months. Normal temperatures during these months vary from near freezing to near 50°F. (Fahrenheit). Normal daily variations of 20°F. occur during these months (13).

(2) Storm orientation. The March 1948 storm center was located near the Lansing area, whereas the April 1947 storm center was located in the headwater areas of the Basin near Jackson. The average rainfall for the Basin for these storms was about the same; however, higher stages were recorded on the Grand River for the March 1948 flood downstream of

Portland than for the April 1947 flood, while upstream of Portland, higher stages were recorded for the April 1947 than for the March 1948 flood. The Grand River maximum flow at Lansing did not contribute significantly to the Grand River maximum flows at Grand Rapids. In addition, the March 1948 maximum flow of the Grand River at Grand Rapids occurred about 18 hours earlier from the midpoint of rainfall excess than the April 1947 maximum flow. Hydrographs of coincidental flows from the Thornapple River, Maple River, and Grand River at Lansing and for the Grand River at Grand Rapids for the April 1947 and March 1948 floods are shown on Plates D-23 and D-24, respectively. This analysis indicates that the Basin has two critical locations where a storm would create the most severe Basin runoff conditions as compared to a similar storm at other locales in the Basin. One center is in the upper Grand River basin upstream from Lansing. A storm over this center would create the most severe runoff conditions for the Lansing area while remaining areas would experience significant runoff conditions. Flood routing studies made on the Upper Grand River basin indicate that maximum flows of the Grand River at Lansing are for the most part due to the coincidental maximum flows from the Red Cedar and the Grand River watershed excluding the Portage River and the area upstream of Jackson. The other center is located downstream from Lansing in the lower Grand River basin. A storm over this center would produce the most severe runoff conditions for the Grand Rapids area while remaining areas would experience significant runoff conditions. Locations of these critical centers are shown on Plate D-25.

(3) Intensity and duration. It is evident that the effective area contributing to Grand River maximum flows within the Basin is limited because of the relatively short durations of the storms. Ninety percent of the total rainfall occurred within 9 hours during the April 1947 storm, and within 12 hours during the March 1958 storm. Rainfall intensity studies made by the U. S. Weather Bureau (14) reveal that as the watershed area increases, the rainfall amounts decrease for the same probability of occurrence. Further studies by the U. S. Weather Bureau indicate that as the

duration of a storm increases, the rainfall intensity decreases for the same probability of occurrence. From an analysis of storm and flood data, it is concluded that a 48-hour to 72-hour rainfall duration of fairly uniform distribution areally would be required in order that the entire upstream drainage area would contribute significantly to maximum Grand River flows at Grand Rapids. Few storms have been recorded when rains have exceeded a 24-hour duration over the entire Basin. The amount of rainfall has been small from storms when rainfall over the entire Basin has exceeded a 24-hour duration.

(4) Basin flood potential. These foregoing factors determine the severity of floods in the Basin. The greatest Basin-wide flood potential occurs in the early spring months of March and April when snow cover is usually present, and light to moderate rainfall of from 12 to 48 hours duration with accompanying rising temperatures occur. Significant Basin-wide flood conditions exist when about 1.5 or more inches of runoff occur. A relation between snow cover frequency of significant Basin-wide floods is shown on Figure D-1. This relationship is based on the estimate that the ratio of snow cover to water equivalents was 10 to 1; that snow was uniformly distributed over the entire Basin; that temperatures were above freezing during the flood; and that the infiltration rate was the mean of the Basin average monthly rate for March and April. These estimates are considered suitable for the purpose intended to reasonably evaluate the possibilities of significant Basin-wide floods for various snow covers. Basin-wide rainfall used was the average of two day intervals of the daily recorded amounts for the months of March and April at Jackson, Lansing, and Grand Rapids, for the normal and extreme periods of rainfall that occurred from 1930 through 1966. Results of this analysis reveal that for the most severe rainfall period recorded, less than a 5 percent chance exists that significant flooding will result any day that snow cover amounts of 10 inches are evident during the March-April months. The Basin monthly average snowfalls for March and April are 7.6 inches and 1.8 inches, respectively.

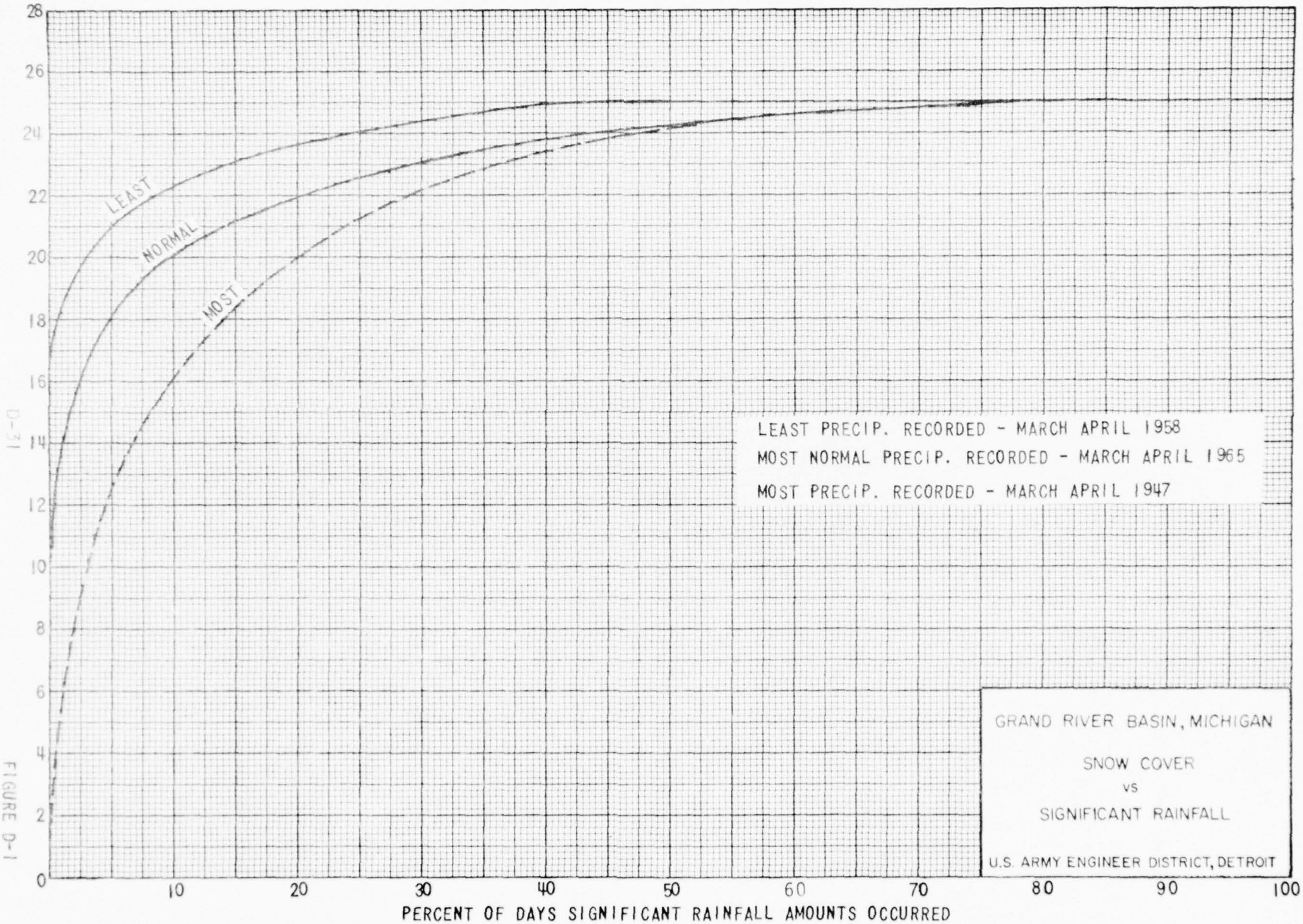

28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
LEAST
NORMAL
MOST
LEAST PRECIP. RECORDED - MARCH APRIL 1958
MOST NORMAL PRECIP. RECORDED - MARCH APRIL 1965
MOST PRECIP. RECORDED - MARCH APRIL 1947
GRAND RIVER BASIN, MICHIGAN
SNOW COVER
vs
SIGNIFICANT RAINFALL
U.S. ARMY ENGINEER DISTRICT, DETROIT
10
20
30
40
50
60
70
80
90
100
PERCENT OF DAYS SIGNIFICANT RAINFALL AMOUNTS OCCURRED

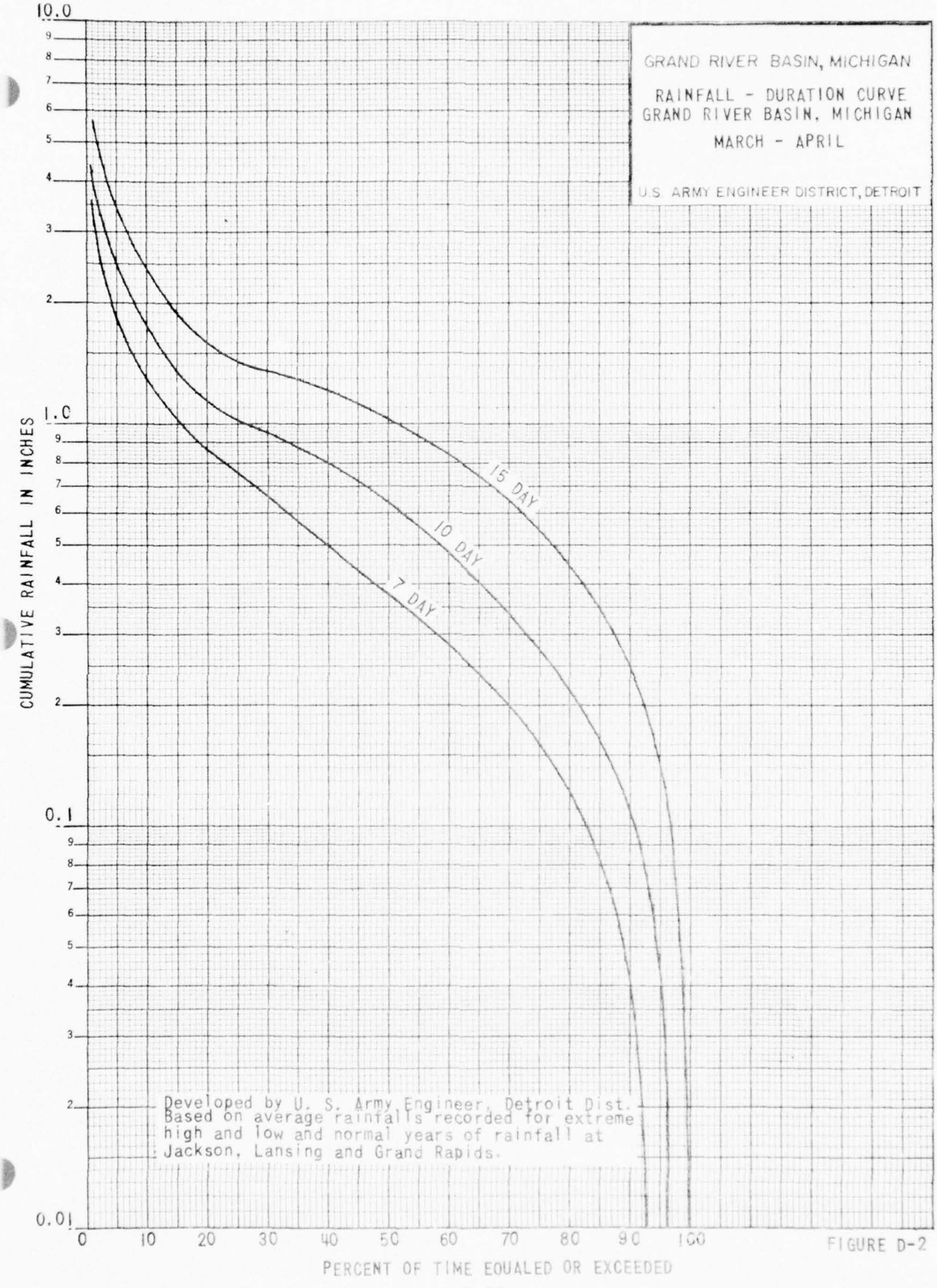
FIGURE D-1

(5) Second storm considerations. The occurrence of a flood producing storm immediately after a flood could produce conditions more serious than those that would have resulted had no reservoir system been in operation. Analyses of Basin rainfall amounts for various durations for the two month period of March and April for the average normal and extreme periods of rainfall from 1930 to 1966 are shown on Figure D-2. These relationships indicate that accumulative significant Basin-wide rainfall within 10 days is experienced only 5 percent of the time during the March-April flood season. It is significant to note that significant Basin-wide rainfall within 10 days following a significant flood-producing storm has never occurred during the past 65 years of record. Based on this information, the occurrence of a second storm does not appear to be a critical factor in the design of a water resource project of this magnitude. It may have an effect worth considering on a smaller watershed.

e. Derivation of procedure for modification of peak-discharge-frequency relationships with varying amounts of storage in potential reservoirs. The effect of potential reservoir sites in the Grand River Basin on peak flood discharges at various major cities in the Basin was determined by flood routing procedures described previously. Reduced peak discharges were plotted for the various storms investigated, assuming that the frequency of the peak discharge remains constant. Plotting a curve of best fit resulted in modified discharge frequency relationships for a given amount at storage for a particular reservoir scheme.

14. FLOOD FREQUENCIES

a. General. Annual maximum runoff frequencies in the Basin were determined as part of the hydrologic studies required for individual project evaluation and design. Methods and procedures used in determining discharge frequency relationships are described in detail in various references (15) (16) (17). Computations were mainly performed by a Burroughs E101 Electronic Computer. One object of this report is to describe the application of these methods and procedures to the Grand River basin. Physical and statistical data for 16 stations within the



GRAND RIVER BASIN, MICHIGAN
RAINFALL - DURATION CURVE
GRAND RIVER BASIN, MICHIGAN
MARCH - APRIL
U.S. ARMY ENGINEER DISTRICT, DETROIT
CUMULATIVE RAINFALL IN INCHES
10.0
1.0
0.1
0.01
15 DAY
10 DAY
7 DAY
Developed by U. S. Army Engineer, Detroit Dist. Based on average rainfalls recorded for extreme high and low and normal years of rainfall at Jackson, Lansing and Grand Rapids.
0
10
20
30
40
50
60
70
80
90
100
PERCENT OF TIME EQUALED OR EXCEEDED

FIGURE D-2

Table D-7

SUMMARY OF PEAK DISCHARGE FREQUENCY STATISTICS

Sta. No.	Stream	Location of Gaging Station	D. A. sq. mi.	Cor-related to *	Statistics based on record			Statistics based on extended records				Statistics based on regression		Final adjusted statistics		
					Years	m	s	Equiv years	m	$\bar{s}$	$\bar{X}^2$	m	$\bar{s}$	Equiv years	m	$\bar{s}$
1	Grand River	Jackson	174	L	23	2.813	.117	31	2.814	.119	.231	3.051	.024	40	2.869	.143
2	Orchard Creek	Munith	49	L	13	2.638	.270	50	2.596	.287	.827	2.569	.238	59	2.592	.280
3	Portage River	Below Lit. Port. Lk.	55	L	13	2.428	.218	49	2.395	.232	.805	2.538	.302	58	2.413	.244
4	Grand River	Eaton Rapids	661	L	8	3.270	.184	50	3.377	.226	.845	3.467	.235	59	3.391	.227
5	Deer Creek	Dansville	16	L	5	2.410	.260	50	2.560	.318	.859	2.260	.196	59	2.517	.303
6	Cedar River	East Lansing	355	L	27	3.334	.208	53	3.361	.232	.857	3.223	.263	62	3.341	.237
7	Grand River	Lansing	1,230	GR	58	3.747	.239	58	3.747	.239	.62**	3.681	.233	67	3.738	.238
8	Lookingglass River	Eagle	281	GR	14	3.083	.242	51	3.072	.261	.854	3.171	.259	60	3.087	.261
9	Grand River	Portland	1,385	L	6	3.665	.187	56	3.822	.221	.965	3.735	.227	65	3.810	.222
10	Maple River	Maple Rapids	434	GR	14	3.307	.290	54	3.293	.315	.930	3.326	.252	63	3.293	.307
11	Grand River	Ionia	2,840	GR	37	4.025	.248	56	4.079	.255	.950	4.000	.209	65	4.068	.249
12	Flat River	Smyrna	528	L	8	3.165	.123	37	3.213	.143	.592	3.455	.184	46	3.262	.152
13	Thornapple River	Hastings	385	GR	14	3.372	.244	51	3.361	.264	.850	3.263	.237	60	3.346	.26
14	Thronapple River	Caledonia	773	GR	7	3.445	.228	50	3.583	.303	.847	3.536	.204	59	3.576	.290
15	Rogue River	Rockford	234	GR	7	3.083	.118	10	3.038	.121	.064	3.175	.191	19	3.130	.158
16	Grand River	Grand Rapids	4,900	L	58 / 19	4.256	.233	58 / 48	4.256	.233	.62**	4.165	.219	67 / 57	4.244	.231

*L indicates Lansing, GR indicates Grand Rapids. Average

**Key stations. No correlation adjustments have been made.

Basin each having discharge records of 5 years or more were used in this study. Data on discharge records used in the study are given in Table D-7.

b. Determination of frequency statistics for individual stations. Computations made of the mean and standard deviation for each station under consideration were in accordance with procedures presented by L. R. Beard (17). An assumption made was that logarithms of peak discharge values would approach a normal frequency distribution. In addition, it was assumed that a 25-year gap in first order measurements at two key stations on the Grand River at Lansing and Grand Rapids could be filled using U. S. Geological Survey estimates of the annual flood from U. S. Weather Bureau records of flood stages.

c. Record adjustment by correlation methods. Computations made for simple linear correlation were accomplished by relating the records of each station in the Basin with the concurrent portions of either the key stations of Lansing or Grand Rapids. The values of the mean (M) and standard deviation ($\bar{S}$), expressed in terms of the logarithms of the maximum flow recorded annually in C.F.S., for the short record stations were adjusted to the longer record key station. This computation increased the reliability of the frequency statistic to the extent that it would approximately equal the reliability that would be obtained if records were actually available for (N) years. The length of the extended period $(N_1') = N_1 + (N_2 - N_1)\,\bar{R}^2$ where:

(N_1') = Equivalent length of record at station 1

N_1 = actual length of record at station 1

N_2' = actual length of record at key station

$\bar{R}$ = coefficient of correlation between station 1 and key station.

Based on the preceding relationships, the average reliability of frequency statistics was increased from 19 to 48 years.

d. Record adjustments by regression methods. Regression methods of relating streamflow statistics utilize physical characteristics of the basins, such as climatic, topographic, and land use. The derivation of the regression equations is explained in detail in paragraph 15(b), flood frequency statistics for ungaged areas, of the appendix. In deriving a regression equation, some degree of error is introduced in estimating the values of dependent variables. The standard error of estimate from the regression is determined as the standard deviation of the difference between the values of the dependent variables as computed and as observed. The effect of error variance in the dependent variable is removed by the following procedures. The standard error of the logarithm of a calculated standard deviation is obtained by the root-mean-square of the standard deviation using a reliability associated with an average length of extended record of 48 years (originally 19 years, but extended in adjusting frequency statistics by correlation alone). The difference of the corresponding variances yields the net variance of the regression. The square root of the net variance, that is the net standard error of the logarithm of the calculated standard deviation, is used in determining a reliability for the regression equations associated with 9 years of record. A single estimate of frequency statistics is made by combining the statistics estimates from the extended record and the regression equation. This is accomplished by weighing them in proportion to their individual reliabilities. The years of record associated with a given degree of reliability are used as the measure of the weight attributable to each value. The composite values of the before and after final adjusted statistics for the sixteen U.S. Geological Survey stream gages are shown in Table D-7, and Figure D-3. The final adjusted annual frequency relationships as determined from the above computed statictics and their confidence limits for these gages are shown on Plates D-3 through D-18.

e. Conclusions. The reliability of frequency statistics is increased in all cases. Correlation analysis increased the average length of record in terms of reliability from 19 to 48 years. Regression analysis increased the reliability 9 additional years. The reliability associated with these

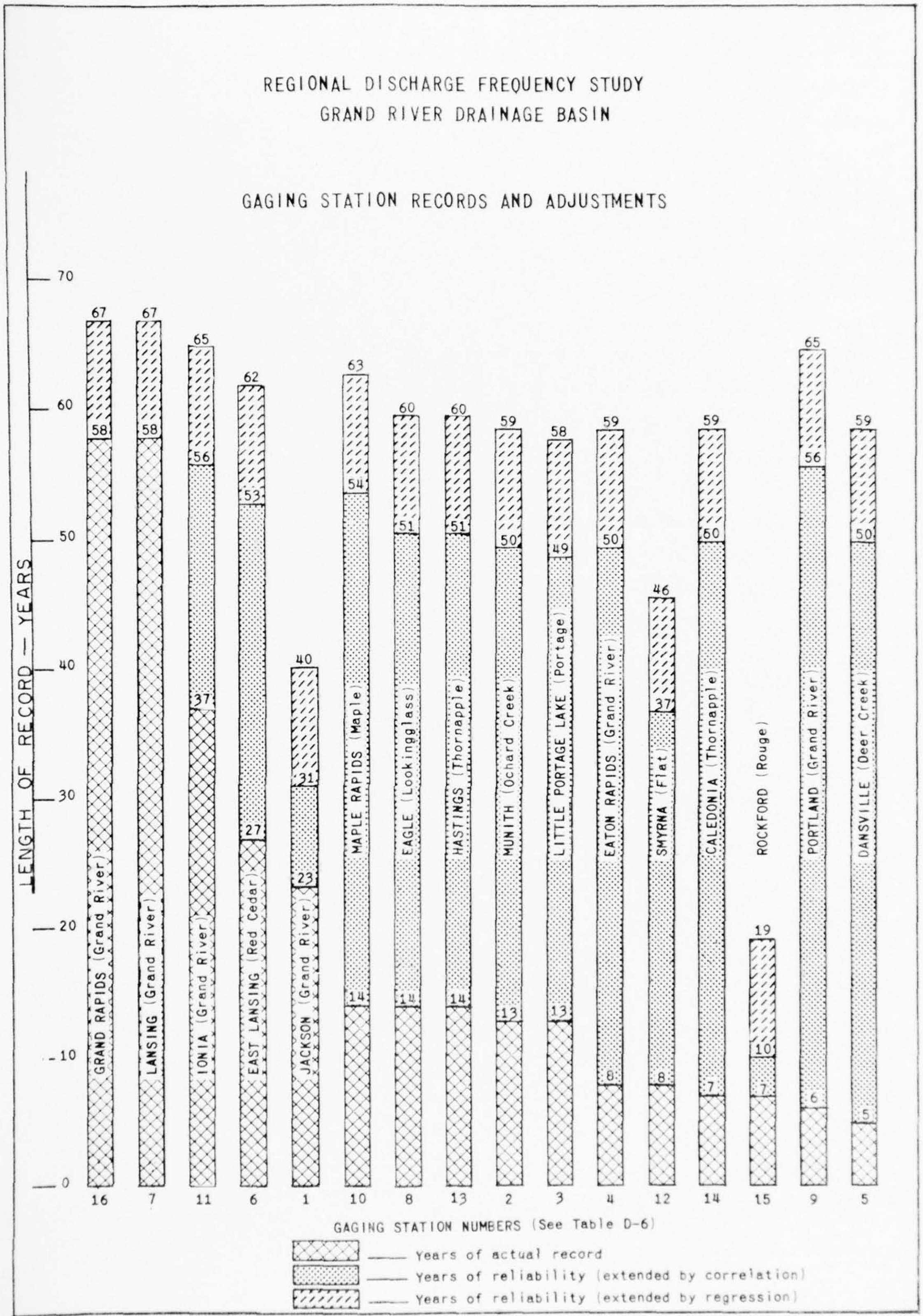

REGIONAL DISCHARGE FREQUENCY STUDY
GRAND RIVER DRAINAGE BASIN
GAGING STATION RECORDS AND ADJUSTMENTS
LENGTH OF RECORD — YEARS
GRAND RAPIDS (Grand River)
LANSING (Grand River)
IONIA (Grand River)
EAST LANSING (Red Cedar)
JACKSON (Grand River)
MAPLE RAPIDS (Maple)
EAGLE (Lookingglass)
HASTINGS (Thornapple)
MUNITH (Ochard Creek)
LITTLE PORTAGE LAKE (Portage)
EATON RAPIDS (Grand River)
SMYRNA (Flat)
CALEDONIA (Thornapple)
ROCKFORD (Rouge)
PORTLAND (Grand River)
DANSVILLE (Deer Creek)
GAGING STATION NUMBERS (See Table D-6)
Years of actual record
Years of reliability (extended by correlation)
Years of reliability (extended by regression)

FIGURE D-3

regression relationships is far less than that obtained by correlation analysis between gaging stations. This is true because the degree of accuracy which develops from adding the number of independent variables relative to area characteristics decreases proportionally with the degree of correlation observed between those records. This then means that the improvement of frequency estimated is inversely proportional to the correlation between records in the Basin. A high degree of correlation is usually due to generalized storms influencing both basins under correlation, and since this type of storm pattern is common over the Grand River basin, the reliability and influence of the regression relationship is markedly less than with correlation relationships. It is recognized that during the period of the study, collection of information on streamflow in the Basin by Federal and State agencies has proceeded. The effect of this has been weighed; the Basin Plan of Development remains unaffected inasmuch as correlation analysis has increased the average length of the record from 19 to 48 years.

15. ANALYSIS OF LOW FLOW PERIODS.

a. General. Low flow periods experienced within the Basin normally occur as a result of extended periods of deficient precipitation and warm temperatures that exist throughout the Basin. The severity of these low flow periods depends on the amount, distribution, and length of time of the low flow. Inspection of streamflow data for the Grand River at Lansing and Grand Rapids indicates that the longest continuous period, common to both stations, of below average annual flows since 1930 is five years. The longest continuous period of below average annual flows at Lansing and Grand Rapids is five years and seven years, respectively. It is noted that the critical five-year period common to both stations is based on the last five years of record through water year 1965, and thus could be extended even further. This information provides an indication of the most critical low flow period experienced in the Basin. Many of the methods and procedures described in the following paragraphs and used in evaluating the various conditions that exist for the various water resource projects are somewhat new. However, these methods and procedures are merely extensions of acceptable methods

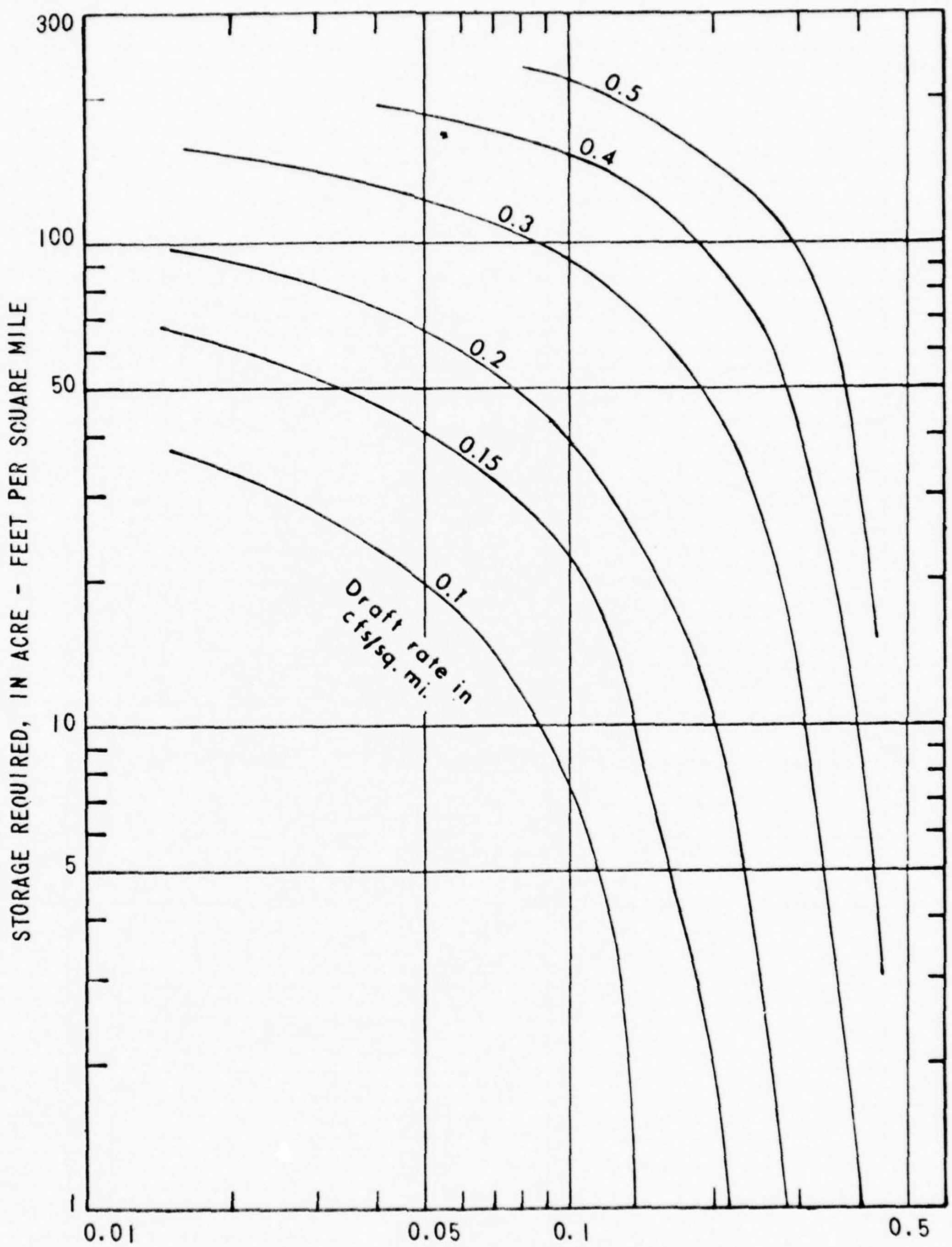
and techniques. The applications of these methods to the Basin are stressed in this report rather than discussions comparing the accuracy and validity of these methods to other procedures. Testing of results obtained by these methods indicates that these methods and procedures provide reasonable estimates of the low flow characteristics of the various water resource projects.

b. Flow-volume relationships. Water supply potential of a stream is evaluated from flow-volume relations. The flow-volume relation defines the storage capacities necessary to maintain preassigned flows for specified durations. Flow-storage relationships are based on mean monthly U. S. Geological Survey streamflow data and disregard the evapotranspiration and sedimentation losses in a reservoir. While these generalizations are adequate for initial studies, it may be necessary to investigate shorter time intervals (weeks, days) and the evapotranspiration, seepage and sedimentation losses that could be expected at each specific site. The flow-storage relationship is based on the assumption that a hypothetical dam is located at the stream gage station under study. Storages are the minimum storages required at the stream gage to guarantee that the indicated preassigned flows decrease as the potential reservoir is moved upstream.

c. Derivation of flow-storage relationships. Storage requirements to maintain the average annual flow and lesser preassigned flows for the period of record are determined from analyses of mass curves developed from streamflow records compiled for nine U. S. Geological stream gage stations. Mass curves are shown on Plates D-3 to D-18. The period of critical drawdown and refill is referred to as the carry over period. For purposes of this study, it is the longest carry over period of a preassigned average flow which occurred during the period of record. Quantitative analyses of streamflow records indicate that the most critical durations of low flows are experienced in the late years of record. Thus, critical carry over periods for the larger supply rates cannot be sufficiently defined. Carry over periods for the larger draft rates that extend beyond the last year of recorded streamflow (1965) are

estimated to be the longest period in which an average of the supply rate occurred during the period of record. Storages required to maintain mean annual and lesser preassigned flows during the period of continuous records and carry over periods associated with these flows are shown on Plates D-3 to D-18. The records from the nine U. S. Geological Survey stream gage stations analyzed do not directly represent the stream flow characteristics for their entire drainage areas. However, they do provide a wide range of coverage in the areal distribution of streamflow characteristics within the Grand River basin. The U. S. Geological Survey has developed flow storage relationships whereby storage requirements can be estimated for an area based on limited streamflow data (18). Basic data used in the development of these relationships were the daily records of discharges at 18 stream gage stations within the Basin, and 5 stations in adjacent basins for a base period of 1945 to 1964. Streamflow records that were developed, for those stations that did not have complete records, by mathematical correlation of streamflow records for those stations that did have complete records are considered representative of the 20-year base period. Definition of the regional draft-storage-frequency relation for the Basin was accomplished by relating the draft storage relationships, as determined by draft-rate lines drawn on the frequency-mass curves, to a parameter that described the low flow characteristics of a stream. The flow that is equaled or exceeded 90% of the time was selected as a suitable parameter index of low flow. Regionalized flow-storage relationships for recurrence intervals of 10 and 20 years are presented as figures D-4 and D-5 respectively. The U. S. Geological Survey has developed low flow characteristics for 56 locations within the Basin. The characteristics were developed for stations where streamflow data were available. Low flow characteristics of stations with limited records were determined by a correlation of instantaneous discharge measurements at the stream gage locations, and the location under study, and the low flow characteristics of the stream gage stations. These data are presented on table D-8. Application of the regional draft-storage relationship developed by the U. S. Geological Survey provides reasonable estimates of the storage requirements to maintain preassigned flows for areas throughout the Basin. The analyses do not include losses due to evapo transpiration, seepage, or sedimentation. The analyses provide data that

GRAND RIVER BASIN
REGIONAL DRAFT - STORAGE
10 YEAR RECURRENCE INTERVAL

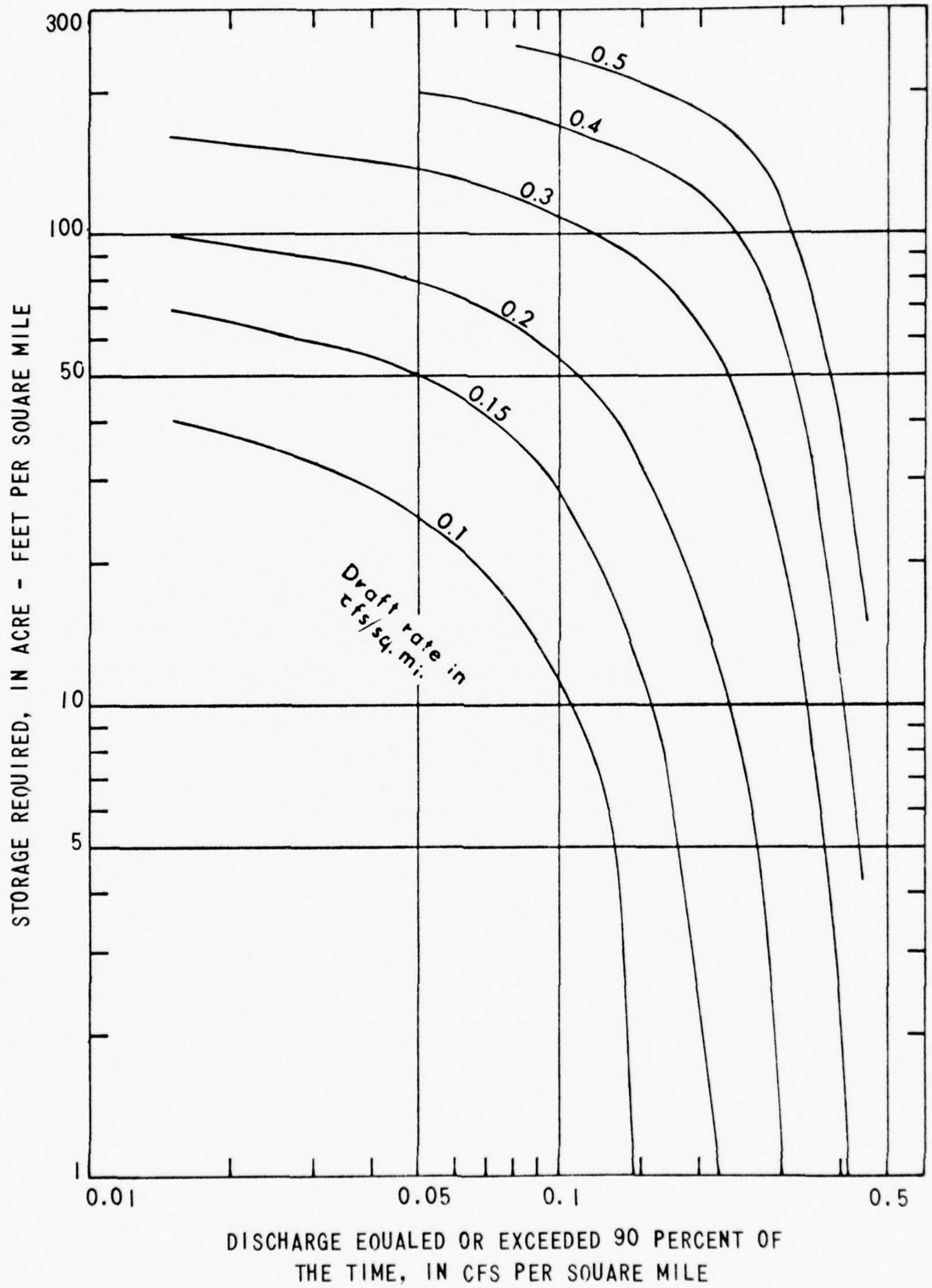


DISCHARGE EQUALED OR EXCEEDED 90 PERCENT OF THE TIME, IN CFS PER SQUARE MILE

PREPARED BY U.S. GEOLOGICAL SURVEY

FIGURE D-4

GRAND RIVER BASIN
REGIONAL DRAFT - STORAGE
20 YEAR RECURRENCE INTERVAL



PREPARED BY U.S. GEOLOGICAL SURVEY FIGURE D-5

Table D-8

VARIATION OF LOW FLOW CHARACTERISTICS

NAME	DRAINAGE AREA	FLOW DURATION 70% C.F.S.M.	80% C.F.S.M.	90% C.F.S.M.	95% C.F.S.M.
Grand R nr. Vandercook*	41.0	.209	.178	.146	.143
Grand R at Jackson	174	.298	.252	.201	.166
Portage R.B.L.F.L. near Munith	55	.156	.116	.073	.040
Orchard Cr. at Munith	49	.165	.124	.094	.073
Batteese Cr. nr. Henietta*	23.8	.222	.168	.080	.042
Hintoan Cr. nr. Leslie	11.2	.250	.205	.161	.133
Sandston Cr. @ Tom. Center *	11.2	.307	.241	.186	.153
Spring Br. nr. Eaton Rapids*	57.0	.201	.157	.114	.087
Grand R. nr. Eaton Rapids	66.1	.264	.211	.158	.133
Cedar Riv nr. Fowlerville*	71.2	.126	.105	.086	.070
Kalamink Cr. at Webberville*	16.5	.145	.133	.109	.096
Squaw Cr. at Williamston	6.08	.065	.040	.025	.013
Doan A. nr. Williamston*	58.4	.113	.094	.074	.059
Deer Cr. nr. Dansville	16.3	.116	.085	.060	.042
Sloan Cr. nr. Williamston	9.34	.044	.028	.018	.012
Cedar R. at East Lansing	355	.152	.121	.090	.070
Sycamore Cr. nr. Mason	39.5	.154	.126	.101	.086
Mud Cr. nr. Mason*	30.8	.120	.091	.062	.045
Sycamore Cr. at Lansing	96.2	.145	.114	.083	.066
Grand R. at Lansing	1230	.215	.170	.134	.105
Sebewa Cr. nr. Sunfield	24.1	.244	.203	.162	.136
Grand R. at Portland	1385	.238	.187	.152	.129
Lookingglass nr. Laingsburg*	88.0	.113	.081	.057	.042
Lookingglass at Dewitt*	234.0	.136	.102	.073	.055
Lookingglass nr. Eagle	281.0	.153	.128	.103	.081
Bean Cr. nr. Ovid*	29.5	.094	.074	.051	.037
Apple Riv @ Ovid*	91.8	.130	.108	.088	.072
L. Maple nr. Laingsburg*	11.4	.078	.061	.048	.039
Maple at Elsie	205.	.146	.117	.093	.078
Pine nr. Pierington*	63.0	.080	.065	.054	.046
Maple R. at Maple Rapids	434	.089	.064	.048	.039
Hayworth Cr. near Maple Rapids*	90.2	.121	.110	.095	.084
Fish Cr. nr. Crystal	92.8	.420	.366	.334	.290
Fish Cr. nr. Carson City*	145	.358	.310	.269	.234
Fish Cr. nr. Hubbardston	157	.394	.336	.287	.248
Stoney Cr. nr. St. Johns	57.9	.094	.086	.078	.072
Muscrat Cr. nr. Riley*	37.2	.118	.096	.081	.072
Stoney Creek at Pawamo*	175	.120	.102	.086	.074
Prairie Cr. nr. Ionia*	89.6	.312	.290	.257	.234
Grand nr. Ionia	2840	.211	.172	.134	.112
Flat at Gowen*	173	.416	.381	.347	.317
Black nr. Greenville*	98.8	.455	.384	.344	.303
Dickeson Cr. nr. Fenwick*	51.7	.367	.309	.251	.212
Flat @ Smyrna	528	.473	.416	.379	.340
Thornapple nr. Potterville*	71.5	.223	.195	.168	.139
Thornapple nr. Vermontville*	160	.150	.131	.106	.087
Quaker Br nr. Nashville	7.6	.407	.342	.276	.236
Thornapple nr. Hastings	385	.285	.246	.203	.171
Bassett Cr. nr. Middleville*	12.1	.603	.578	.545	.512
Coldwater @ Freeport*	83.5	.455	.335	.240	.179
Coldwater nr. Middleville*	185	.297	.270	.233	.210
Thornapple nr. Caldonia	773	.349	.310	.272	.232
Rogue nr. Sparta*	155	.503	.445	.368	.335
Rogue nr. Rockford	234	.576	.512	.427	.384
Grand at Grand Rapids	4900	.255	.224	.186	.163
Crockery Cr. nr. Nunica*	126	.277	.238	.198	.166

*Partial-Record Station

are used in comparing the potential water supply yields of areas located throughout the Basin. It is noted that while these data were developed for 56 locations, they may reasonably be assumed for comparison purposes to be also representative of their upstream areas.

d. Optimum flow-storage utilization. Flow storage relationships developed and shown on plates D-3 to D-18 are expressed in percentages of ultimate flow and storage. The ultimate flow and ultimate storage are at the stream gage station. The rate of increase is greater than the increase in storage for the lower percents of site development percentages. This rate decreases until the rate of increase in storage exceeds the rate of increase in discharge. The point where the rate of increase in discharge equals the rate of increase in storage is referred to as the optimum flow storage development, and represents the greatest augmentation of low flow per unit of storage. This point does not necessarily define the best development of the water resources of the site, but it does indicate the most efficient storage for low flows.

e. Reliability of reservoirs (19)

(1) Derivation of storage-duration-frequency relationships. An important aspect of flow augmentation is the capability of a reservoir to maintain critical flow requirements. Capability of various flow-storage relationships have been developed by a method devised by John B. Stall (20). These relationships were developed for nine U.S. Geological Survey stream gage stations. They show the time that a selected constant flow could be maintained by a calculated storage capacity. The relationships represent storage requirements that would be needed to maintain constant demands for from 80 percent to 98 percent of the time for durations of from 2 months to 36 months. The durations represent the time from the beginning of the critical period until the reservoir had reached its minimum elevation. These relationships are shown on plates D-3 to D-18.

(2) The effects of variable demands on reservoir storage requirements. The effect of variable demands on a reservoir is determined for individual sites by applying the critical demands for various durations and reliabilities and determining storage requirements by Stall's Method. Selection of storages based on the most critical demand for the shortest time interval would normally require such excessive storages that the critical demand rate could be supplied for longer periods of duration than would be necessary. Selection of storages based on the most critical demand for longer time intervals would normally result in insufficient storage, such that the critical rates would be supplied for shorter durations than are required. The selected initial design capacity is that point where the duration of the critical demand equals the time from the beginning of the critical period until the reservoir reaches its minimum elevation for the given draft rate. This storage is the capacity that is required to supply the critical demand for the critical duration when these demands are required.

(3) The effects of variable dependencies on reservoir storage requirements. Where storage requirements are being evaluated for different dependabilities, a successive trial procedure is used for determining the amount of storage required to meet the demands (21). This procedure determines the combined optimum use of the trial storages to meet the various needs.

(4) Uncontrolled flow effects on required upstream reservoir storages. Depending upon the needs, uncontrolled flows may effect storage requirements necessary to maintain a given supply. The extent of these effects depends on the yields of the uncontrolled areas and the reservoirs. When the uncontrolled yields are greater than the controlled yields, the effects of the uncontrolled flows on the critical demands are determined with the resultant demand from the controlled flows used to determine the storage required to maintain demands. When the controlled flows have higher yields than the uncontrolled flows, the ability of the controlled flows to maintain the critical demands is determined. The average yield of the uncontrolled area is determined for this critical demand, and the resultant demand from the controlled area is used to determine the storage required to maintain the resultant demand. For

those instances where the reservoir is the only source of supply, uncontrolled flows have no effect on reservoir storage requirements. For those instances where the uncontrolled flows are used to meet various needs, the uncontrolled flows affect the storage requirements of a reservoir. These effects are evaluated by application of the critical demand rate to the given reliability for the storage-duration relationship developed for the higher yields of either the uncontrolled or the controlled areas. The average yield for the given critical period is subtracted from the total demand. This resultant demand is applied to the given reliability for the storage-duration relationship developed for the reservoir site, with the storage required to maintain the resultant demand determined.

(5) More than one reservoir in system. When more than one reservoir could supply water, the storages required are based on the assumption that only one reservoir exists. The individual storage-duration-frequency characteristics of the reservoir sites are combined directly, as are the characteristics of the uncontrolled areas. The storage requirements are evaluated as described in previous subparagraph(4).

16. STREAMFLOW DATA FOR UNGAGED AREAS

a. General, Analyses of streamflow characteristics for specific locations where records are not available are made based on regionalizing recorded streamflow data. The generation of such synthetic data provides a valuable tool for the purpose of evaluating the streamflow characteristics of many different locations with regard to their flood potential and their ability to supply water. The specific flood characteristics of interest for any given location are the flood frequency potential and the flood discharges resulting from any given storm. The specific streamflow data concerning the water supply capabilities of a stream are the flow-volume-duration-frequency characteristics of the stream. Methods and techniques are developed whereby the flood frequency, the flood runoff, and the water supply capabilities can be determined for any location within the Basin (22) (23). The methods and techniques are described in the following paragraphs.

b. Flood-frequency statistics for ungaged areas. In order to correlate flood runoff data between subareas or tributary basins within the Grand River basin, the assumption is made that climate, topography, land use, land classes (soils, etc.) and vegetation, are reasonably uniform throughout the entire Basin. It is also assumed that the frequency statistics expressed as the mean (M) and standard deviation ($\bar{S}$) may be expressed in terms of a linear function of independent natural drainage characteristics. The independent variables analyzed for correlation on the Grand River basin are:

Average Stream Slope
Stream Length
Average Annual Precipitation
Drainage Area

Each of these independent variables was tested against the dependent variables (mean and standard deviation) using scatter diagrams and by computing the simple coefficient of correlation of their logarithms to determine their worth. Two multiple linear regression equations were selected of the form:

$$X_1 = a + b_2 + b_3 X_3 + b_4 X_4 + b_5 X_5.$$

Regression coefficients were determined for a b_2, b_3, b_4, and b_5 by computations by the method of least squares. These computations resulted in the following two equations relating the mean and standard deviation to drainage area characteristics:

$$M = 1.300 + 0.35 \log S + 0.049 \log L - (0.65 \log P/10) + .802 \log D.A.$$

$$\log 10\ \bar{S} = 1.179 - .526 \log S + .0262 \log L - (0.834 \log P/10)$$

where:

M = mean of the logarithms of the annual flood peaks
$\bar{S}$ = standard deviation of the frequency curve
Log 10 $\bar{S}$ = log of (10 x standard deviation)
S = average stream slope in feet per mile*
L = stream length in miles*
P = average annual precipitation in inches
D. A. = drainage area in square miles

* Determined for the main stream from the gaging station to the headwaters.

Perhaps an explanation of the negative sign associated with the coefficient of precipitation is that the variables are not entirely independent of one another. The mathematical solution of these parameters has built in, so to speak, a relationship between these parameters such that inspection of one of these parameters cannot be accurately made without realizing the change in the other variables. Inspection of the equation for the mean discharge would lead to an incorrect statement that by increasing the annual rate of precipitation, a decrease in the amount of the mean annual discharge would result. Rather, the correct interpretation of this relationship is that for areas where greater annual precipitation amounts exist, the drainage areas, and stream slopes and lengths are such that the mean discharge increased. There is no area with similar characteristics, drainage area, slope, and stream lengths, that has a smaller mean discharge for a greater amount of annual precipitation.

c. Flood discharges for ungaged areas. Flood discharges for an area are most commonly expressed in the form of a hydrograph. A discharge hydrograph is a plot of discharge against time. Analyses of recorded hydrographs of streamflow and related climatic and physiographic characteristics suggest methods of utilizing these deduced factors in developing hydrographs for ungaged areas. When physiographic and climatic components are fairly uniform for an area, a simplified procedure is used where the discharges are in direct proportion to the size of the drainage areas. The method most commonly used in the investigation of flood discharges for ungaged areas is the "Unitgraph" method. Data required in this method are unit hydrographs (a hydrograph representing one inch of direct runoff from a rainfall of some unit duration and specific areal distribution), base flows (base flow is comprised of flow contributed by the groundwater table), infiltration losses, and the time distribution and intensity of precipitation. Unit hydrographs have been developed for several subareas that comprise the entire Basin upstream of Grand Rapids. These subareas are shown on plate D-26. Six of the unitgraphs were developed directly from recorded streamflow data available for a particular location. Twenty-nine of the unitgraphs were synthetically developed by applying characteristics of those six unitgraphs where stream-

Table D-9

6-HOUR UNIT HYDROGRAPHS - GRAND RIVER BASIN

		Grand River at Jackson	Grand River just U/S of Portage R.	Portage River D/S Little Portage Lake	Portage River just U/S of Orchard Cr.	Orchard Creek at Munith	Orchard Creek at Mouth
Zone No.		1	2	3	4	5	6
D.A.	Sq. Mi.	175.0	13.6	57.0	6.71	50.8	3.7
L	Mi.						
L_{ca}	Mi.						
Q_p	C.F.S.	GAGE		GAGE		GAGE	
q_{pr}	C.F.S./Sq. Mi.						
t_{pr}	Hrs.						
W_{50}	Hrs.						
W_{75}	Hrs.						
Base L	Hrs.						
t_r	Hrs.						

DISCHARGE C.F.S.

HOURS						
0	(1) 0	(3) 0	(1) 0	(3) 0	(1) 0	(3) 0
6	0	85	5	42	0	23
12	64	277	119	137	9	76
18	97	299	314	148	15	82
24	113	256	342	127	33	70
30	145	203	391	100	70	56
36	161	149	527	74	137	41
42	209	107	524	53	201	29
48	241	64	491	32	243	18
54	258	32	450	16	274	9
60	306	11	395	5	293	3
66	370	0	342	0	316	0
72	386		282		332	
78	419		211		346	
84	451		178		343	
90	483		152		335	
96	531		126		320	
102	547		108		301	
108	563		91		280	
114	596		76		255	
120	596		63		234	
126	612		56		214	
132	628		45		189	
138	628		37		170	
144	628		29		152	
150	612		23		135	
156	596		17		119	
162	570		11		103	
168	560		9		82	
174	534		8		71	
180	525		7		57	
186	515		5		52	
192	489		3		46	
198	480		0		38	
204	454				30	
210	428				21	
216	402				14	
222	377				6	
228	335				0	
234	309					
240	283					
246	274					
252	248					
258	238					
264	212					
270	187					
276	177					
282	151					
288	126					
294	116					
300	90					
306	80					
312	71					
318	61					
324	48					
330	32					
336	0					
342						

(1) Unit Hydrograph developed from gage records

(2) Unit Hydrograph developed synthetically

(3) Unit Hydrograph developed from areal relationship with Zone No. 38

Sheet 1

Table D-9 (Cont'd.)

6-HOUR UNIT HYDROGRAPHS - GRAND RIVER BASIN

		Portage River at Mouth	Grand River at Rives Junction	Grand River just U/S of Sandstone Cr.	Sandstone Creek at Mouth	Grand River at Onondaga	Grand River at Eaton Rapids
Zone No.		7	8	9	10	12	13
D.A.	Sq. Mi.	64.4	37.7	59.2	89.0	11.2	135.3
L	Mi.	22.9	9.4	12.6	21.6		22.5
L_{ca}	Mi.	11.1	2.6	6.6	10.8		10.2
Q_p	C.F.S.	869	932	1,000	1,290		1,665
q_{pr}	C.F.S./Sq. Mi.	13.5	24.7	17.9	14.5		12.3
t_{pr}	Hrs.	22.8	11.7	16.9	18.0		25.9
W_{50}	Hrs.	45.0	24.0	33.0	36.0		47
W_{75}	Hrs.	26.0	14.0	19.5	22.0		26
Base L	Hrs.	120.0	72.0	96.0	114		144
t_r	Hrs.	4.2	2.1	3.1	3.1		4.65
				DISCHARGE C.F.S.			
HOURS							
0		(2) 0	(2) 0	(2) 0	(2) 0	(3) 0	(2) 0
6		90	160	170	200	70	290
12		430	800	570	750	229	710
18		730	920	1,030	1,220	247	1,270
24		860	740	1,050	1,290	211	1,665
30		840	540	920	1,190	167	1,645
36		740	370	740	970	123	1,490
42		650	250	580	760	88	1,320
48		570	160	440	625	53	1,140
54		480	90	320	530	26	970
60		400	40	220	450	9	820
66		320	10	150	330	0	690
72		250	0	90	320		570
78		190		50	260		470
84		140		40	210		380
90		100		10	160		310
96		60		0	120		250
102		40			80		190
108		20			40		140
114		10			0		100
120							70
126							50
132							30
138							15
144							0
150							
156							
162							
168							
174							
180							
186							
192							
198							
204							
210							
216							
222							
228							
234							
240							
246							
252							
258							
264							
270							
276							
282							
288							
294							
300							
306							
312							
318							
324							
330							
336							
342							

(1) Unit Hydrograph developed from gage records

(2) Unit Hydrograph developed synthetically

(3) Unit Hydrograph developed from areal relationship with Zone No. 38

Table D-9 (Cont'd.)

6-HOUR UNIT HYDROGRAPHS - GRAND RIVER BASIN

		Grand River at Dimondale	Grand River at Millett	Grand River just U/S of Red Cedar River	Red Cedar at Williamston	Red Cedar at Okemos	Red Cedar at East Lansing	Sycamore at Mouth
Zone No.		14	15	16	17a	17b	18	19
D.A.	Sq. Mi.	62.9	16.3	16.6	227.8	115.3	7.9	110.2
L	Mi.	12.9	8.0	7.9	25.6	29.0		23.8
L_{ca}	Mi.	7.2	3.9	3.8	12.5	11.8		14.0
Q_p	C.F.S.	1,089	383	389	2,337	1,173		1,120
q_{pr}	C.F.S./Sq. Mi.	17.3	23.5	23.4	10.28	10.2		10.2
t_{pr}	Hrs.	17.4	12.6	13.4	28.4	28.6		28.4
W_{50}	Hrs.	33.0	25.0	25.0	60	58		54.0
W_{75}	Hrs.	19.0	14.0	15.0	34	33		34.0
Base L	Hrs.	96.0	72.0	72.0	132	150		162.0
t_r	Hrs.	3.2	2.9	2.3	5.2	5.24		5.2

DISCHARGE C.F.S.

HOURS	Grand River at Dimondale	Grand River at Millett	Grand River just U/S of Red Cedar River	Red Cedar at Williamston	Red Cedar at Okemos	Red Cedar at East Lansing	Sycamore at Mouth
	(2)	(2)	(2)	(2)	(2)	(3)	(2)
0	0	0	0	0	0	0	0
6	240	130	130	320	140	50	130
12	710	360	360	760	350	161	330
18	1,060	380	380	1,390	660	173	680
24	1,060	280	280	2,150	1,020	149	1,000
30	880	220	220	2,320	1,165	118	1,110
36	700	160	160	2,270	1,160	87	1,110
42	570	100	100	2,100	1,080	62	1,060
48	450	60	60	1,920	990	37	960
54	350	40	40	1,750	890	19	840
60	270	20	20	1,590	810	6	730
66	200	10	10	1,430	720	0	620
72	140	0	0	1,270	640		530
78	80			1,120	550		460
84	50			970	480		400
90	20			820	400		350
96	0			680	340		300
102				535	280		250
108				405	230		220
114				280	180		180
120				165	130		160
126				60	90		130
132				0	50		100
138					30		80
144					10		60
150					0		40
156							20
162							0
168							
174							
180							
186							
192							
198							
204							
210							
216							
222							
228							
234							
240							
246							
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264							
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312							
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324							
330							
336							
342							

(1) Unit Hydrograph developed from gage records

(2) Unit Hydrograph developed synthetically

(3) Unit Hydrograph developed from areal relationship with Zone No. 38

Table D-[illegible] (Cont'd.)

6-HOUR UNIT HYDROGRAPHS - GRAND RIVER BASIN

		Red Cedar at Lansing	Grand River at Grand Ledge	Grand River at Portland	Looking-glass River at Eagle	Looking-glass River at Mouth	Grand River at Lyons	Maple River at Maple Rapids	Maple River at Mouth
Zone No.		20	22	23	24	25	26	27	28
D.A.	Sq. Mi.	1.1	45.3	108.7	286.0	26.0	45.4	423.0	365.0
L	Mi.		12.2	29.1		10.2	19.0		40.0
L_{ca}	Mi.		6.0	13.5		4.9	10.8		15.0
Q_p	C.F.S.		834	1,254		534	630	GAGE	3,734
q_{pr}	C.F.S./Sq. Mi.		18.4	11.5		20.6	13.9		10.2
t_{pr}	Hrs.		16.3	26.9		14.5	22.1		30.6
W_{50}	Hrs.		32.0	56.0	(Gage)	29.0	43.0		62.0
W_{75}	Hrs.		18.0	32.0		17.0	25.0		36.0
Base L	Hrs.		96.0	120.0		72.0	108.0		144.0
t_r	Hrs.		3.0	4.9		2.6	4.0		5.6
		DISCHARGE C.F.S.							
HOURS									
0		(3) 0	(2) 0	(2) 0	(1) 0	(2) 0	(2) 0	(1) 0	(2) 0
6		7	240	240	338	175	160	19	350
12		23	640	600	480	425	370	410	900
18		25	830	910	838	534	460	484	1,840
24		22	790	1,150	839	485	620	809	2,980
30		17	620	1,250	1,132	380	610	2,489	3,680
36		13	480	1,200	1,132	285	540	2,778	3,734
42		9	370	1,090	996	220	460	3,072	3,630
48		5	290	1,000	793	155	380	3,298	3,350
54		3	220	890	656	105	310	3,386	3,070
60		1	160	780	606	60	250	3,228	2,780
66		0	110	680	577	25	200	2,982	2,490
72			70	570	562	0	160	2,760	2,210
78			40	460	556		120	2,526	1,930
84			20	340	550		90	2,268	1,680
90			10	240	547		60	2,038	1,350
96			0	160	559		30	1,818	1,060
102				100	576		20	1,612	760
108				50	599		0	1,422	550
114				20	613			1,232	390
120				0	634			1,072	270
126					647			906	170
132					660			772	100
138					666			660	30
144					673			559	0
150					680			441	
156					690			358	
162					714			277	
168					717			242	
174					725			228	
180					723			212	
186					708			204	
192					694			180	
198					676			167	
204					657			139	
210					634			104	
216					595			70	
222					572			43	
228					547			13	
234					522			0	
240					491				
246					454				
252					432				
258					396				
264					365				
270					347				
276					310				
282					282				
288					254				
294					240				
300					201				
306					183				
312					162				
318					127				
324					100				
330					68				
336					44				
342					0				

(1) Unit Hydrograph developed from gage records

(2) Unit Hydrograph developed synthetically

(3) Unit Hydrograph developed from areal relationship with Zone No. 38

Sheet 4

Table D-9 (Cont'd.)

6-HOUR UNIT HYDROGRAPHS - GRAND RIVER BASIN

		Stoney Creek at Mouth	Grand River at Ionia	Grand River just U/S Lake Cr.	Grand River at Lowell	Flat River at Mouth	Grand River just U/S of Thornapple R.	Thornapple at Hastings
Zone No.		29	31	32	33	34	35	36
D.A.	Sq. Mi.	182.0	172.0	93.6	57.6	555.7	38.0	407.0
L	Mi.	31.8	24.0	16.3	18.3	60.0	8.1	
L_{ca}	Mi.	16.5	7.5	6.3	9.7	32.0	4.9	
Q_p	C.F.S.	1,940	2,355	1,572	835	4,073	829	GAGE
q_{pr}	C.F.S./Sq. Mi.	10.6	13.7	16.8	14.5	7.3	21.8	
t_{pr}	Hrs.	29.3	22.0	18.0	21.2	43.3	13.5	
W_{50}	Hrs.	61.0	44.0	36.0	41.0	90.0	27.5	
W_{75}	Hrs.	35.0	26.0	21.0	24.5	51.0	16.0	
Base L	Hrs.	132.0	108.0	96.0	96.0	180.0	72.0	
t_r	Hrs.	5.3	4.0	3.3	3.9	7.9	2.5	

DISCHARGE C.F.S.

HOURS	Zone 29	Zone 31	Zone 32	Zone 33	Zone 34	Zone 35	Zone 36
0	(2) 0	(2) 0	(2) 0	(2) 0	(2) 0	(2) 0	(1) 0
6	110	670	420	200	210	320	98
12	590	1,690	1,220	480	920	740	281
18	1,220	2,190	1,530	750	1,630	830	582
24	1,720	2,360	1,560	840	2,350	690	933
30	1,930	2,250	1,280	820	3,070	520	1,330
36	1,900	1,910	1,030	710	3,790	380	2,052
42	1,780	1,610	840	610	4,040	260	2,640
48	1,660	1,340	670	500	4,010	180	3,134
54	1,510	1,110	520	400	3,850	110	3,336
60	1,360	920	380	310	3,680	60	3,405
66	1,210	760	260	220	3,490	10	3,305
72	1,060	600	170	150	3,310	0	3,108
78	920	470	90	100	3,120		2,875
84	770	340	50	50	2,920		2,602
90	620	230	20	20	2,720		2,334
96	480	120	0	0	2,530		2,077
102	350	50			2,320		1,804
108	240	0			2,130		1,548
114	140				1,910		1,328
120	50				1,700		1,089
126	10				1,500		874
132	0				1,270		752
138					1,050		572
144					820		432
150					620		320
156					450		248
162					300		170
168					180		105
174					70		68
180					0		32
186							21
192							10
198							0
204							
210							
216							
222							
228							
234							
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(1) Unit Hydrograph developed from gage records

(2) Unit Hydrograph developed synthetically

(3) Unit Hydrograph developed from areal relationship with Zone No. 38

Table D-9 (Cont'd.)

6-HOUR UNIT HYDROGRAPHS - GRAND RIVER BASIN

		Thornapple at Mouth	Grand River at Honey Creek	Grand River just U/S Rouge R.	Rogue River at Mouth	Grand River at Plainfield	Grand River at Grand Rapids	Grand River at Grandville
Zone No.		37	38	39	40	41	42	43
D.A.	Sq. Mi.	464.2	12.7	70.2	261.3	35.5	44.6	87.4
L	Mi.	45.2	8.6	12.5	47.0	13.6	12.1	25.3
L_{ca}	Mi.	22.3	4.3	5.8	30.0	4.7	6.1	10.4
Q_p	C.F.S.	3,830	281	1,300	2,090	676	825	112.7
q_{pr}	C.F.S./Sq. Mi.	8.8	22.1	18.5	8.0	19.2	18.5	12.9
t_{pr}	Hrs.	35.8	13.3	16.2	39.5	15.6	16.3	23.9
W_{50}	Hrs.	74.0	28.0	33.0	81.0	30.0	32.0	45.0
W_{75}	Hrs.	42.0	16.0	18.0	47.0	17.5	18.0	27.0
Base L	Hrs.	192	66.0	96.0	168.0	96.0	96.0	120.0
t_r	Hrs.	6.5	2.4	2.9	7.2	2.8	3.0	4.4

DISCHARGE C.F.S.

HOURS	Thornapple at Mouth	Grand River at Honey Creek	Grand River just U/S Rouge R.	Rogue River at Mouth	Grand River at Plainfield	Grand River at Grand Rapids	Grand River at Grandville
0	(2) 0	(2) 0	(2) 0	(2) 0	(2) 0	(2) 0	(2) 0
6	240	80	310	210	200	250	250
12	700	260	1,030	560	520	640	580
18	1,600	280	1,290	900	670	820	870
24	2,650	240	1,220	1,250	620	760	1,100
30	3,600	190	950	1,590	480	600	1,110
36	3,820	140	730	1,950	360	480	1,020
42	3,810	100	580	2,090	270	380	910
48	3,600	60	460	2,070	200	310	770
54	3,370	30	350	1,980	150	240	630
60	3,150	10	260	1,880	110	180	500
66	2,900	0	180	1,770	90	120	410
72	2,700		120	1,660	60	80	330
78	2,480		60	1,540	40	50	270
84	2,260		30	1,410	20	20	220
90	2,040		10	1,280	10	10	170
96	1,850		0	1,160	0	0	120
102	1,630			1,020			80
108	1,440			890			50
114	1,250			760			20
120	1,070			630			0
126	910			500			
132	750			380			
138	600			260			
144	470			160			
150	260			100			
156	260			60			
162	180			20			
168	120			0			
174	60						
180	30						
186	10						
192	0						
198							
204							
210							
216							
222							
228							
234							
240							
246							
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(1) Unit Hydrograph developed from gage records

(2) Unit Hydrograph developed synthetically

(3) Unit Hydrograph developed from areal relationship with Zone No. 38

flow data were available. Six of the unitgraphs were developed by a proportionate discharge-area relationship. Unitgraph data for these subareas are presented in table D-9. Flood discharges for the various subareas are determined by applying the estimated rainfall excess amounts during a 6-hour duration from the occurrence of an actual or synthetic storm to the 6-hour unit hydrograph. Estimated rainfall excess amounts are determined by methods described in paragraph 23, Correlation of Data, of this appendix.

d. Water supply capabilities for ungaged areas. Water supply capabilities for ungaged areas are reasonably evaluated by a volume-frequency-duration analysis of monthly streamflow data. The generation of synthetic streamflows for ungaged areas is accomplished by relating physiographical and climatic components of gaged areas to these components of an ungaged area. A method has been developed that describes, evaluates, and relates these components such that monthly streamflows can be generated for an ungaged area. Physiographic components define to a degree an area's groundwater and runoff characteristics. It is considered reasonable to assume that the monthly climatic conditions that produce a flow that is exceeded any given percent of time, except extreme percents, at one location would produce another flow that is exceeded the same given percent of time, provided the locations are within a reasonable distance from one another. The actual variation in the flow at the two locations for the same exceedence frequency is an indication of the difference of physiographic conditions between the areas. It is considered reasonable to assume that for an area of uniform physiographic characteristics, the runoff per square mile of drainage area would vary depending on the precipitation distribution over the area. When these factors are combined, they provide a procedure that realizes to a degree the variation in the climatic and physiographic characteristics of runoff within a basin. Data used in this method are recorded monthly streamflow data, and coincidental flow-frequency relationships for the stream gages and the ungaged area. Flow-frequency relationships for ungaged areas may be obtained by direct application of the nearest location where a flow-frequency relationship has been developed, or they may be estimated by a composite analysis of several flow-frequency relationships near the ungaged area. Tests performed by attempting to reproduce recorded streamflow data indicated that this procedure provided reasonable estimates of monthly streamflows. Initial storages to meet given demands for ungaged locations are estimated from application of the

90% low flow characteristics of the area under study to regionalized data developed by the U. S. Geological Survey and described in paragraph 14c., Derivation of flow-storage relationships, of this appendix. Generated monthly streamflows are analyzed as described in paragraph 14e., Reliability of reservoirs, to determine the water supply reliabilities and capabilities of those sites considered feasible.

SECTION IV
EVAPOTRANSPIRATION

17. GENERAL

Evapotranspiration refers to water lost by evaporation from surface waters and from plant life. Water loss from surface waters is referred to as surface water evaporation. Water loss through evaporation by plant life is referred to as transpiration. The primary concern with evapotranspiration is in the realm of water losses from reservoirs and streams. The design and operation of reservoirs must allow for the effects of evaporation on dependable minimum yields. Methods used in evaluating these losses are briefly described in the following paragraphs (24).

18. SURFACE WATER EVAPORATION

Monthly pan evaporation losses have been recorded at East Lansing since 1949 by the U. S. Weather Bureau. This is the only station within the Grand River basin where evaporation losses are recorded. Inspection of evaporation losses recorded at other localities in the State of Michigan indicates that the pan evaporation rates recorded at East Lansing are applicable throughout the entire basin. Monthly average pan evaporation rates for East Lansing, South Haven, Dearborn, Lake City and Lupton are shown in plate D-27. The U. S. Weather Bureau has developed a method of computing lake evaporation amounts from pan evaporation amounts (25). Results of this study indicate that lake evaporation amounts are about 76 percent of pan evaporation amounts within the Grand River basin. This factor is also applicable to streamwater surfaces. Pan and lake evaporation amounts that have been recorded and computed, respectively, for the East Lansing station are shown on table D-10. The maximum recorded pan evaporation amount of 30.63 inches for the four-month period of May through August occurred in 1962. The normal pan evaporation for this period is 27.41 inches.

TABLE D-10 June 1967

PAN AND LAKE EVAPORATION

EAST LANSING HORTICULTURE FARM

	MAY		JUNE		JULY		AUG.		SEPT.		OCT.		ANNUAL	
Year	Pan In.	Lake In.	Pan In.	Lake In.	Pan In.	Lake In.	Pan In.	Lake In.	Pan In.	Lake In.	Pan In.	Lake In.	Pan In.	Lake In.
1949	7.83	5.95	8.61	6.54	7.99	6.07	6.47	4.92	4.89	3.72	4.00	3.04	39.79	30.24
1950	6.53	4.96	7.75	5.89	-	-	6.64	5.05	3.99	3.03	3.19	2.42	35.58	27.04
1951	6.13	4.66	5.25	3.99	7.09	5.39	5.76	4.38	4.79	3.64	2.95	2.24	31.97	24.22
1952	6.79	5.16	8.71	6.60	8.47	6.44	6.66	5.06	4.84	3.68	4.06	3.09	39.53	30.04
1953	5.04	3.83	7.76	5.90	8.25	6.27	7.17	5.45	5.23	3.97	3.94	2.99	36.39	27.57
1954	6.12	4.65	6.66	5.06	7.10	5.40	6.03	4.58	4.87	3.70	2.52	1.91	33.30	25.31
1955	6.27	4.76	7.74	5.88	7.89	6.00	7.28	5.53	5.89	4.48	3.48	2.64	38.55	29.30
1956	5.69	4.32	7.45	5.66	7.12	5.41	5.76	4.38	5.61	4.26	4.72	3.59	36.35	27.63
1957	5.78	4.39	6.77	5.14	7.74	5.88	6.59	5.01	3.99	3.03	2.74	2.08	33.61	25.54
1958	8.11	6.09	6.62	5.03	6.65	5.05	7.01	5.33	4.15	3.15	3.61	2.74	36.15	27.47
1959	6.31	4.79	8.16	6.20	-	-	5.87	4.46	4.93	3.75	2.28	1.73	35.03	26.62
1960	4.64	3.53	6.82	5.18	7.89	6.00	5.61	4.26	4.60	3.50	2.97	2.26	32.53	24.72
1961	6.63	5.04	6.90	5.24	6.60	5.02	5.34	4.06	4.14	3.15	2.64	2.01	32.25	24.51
1962	6.90	5.24	7.21	5.48	6.96	5.29	6.76	5.14	4.83	3.67	2.60	1.98	35.26	26.00
1963	5.35	4.07	6.95	5.28	7.56	5.74	5.63	4.28	3.86	2.93	3.93	2.99	33.28	25.30
1964	6.88	5.23	7.80	5.93	7.44	5.65	6.28	4.77	4.34	3.30	2.61	1.98	35.35	26.97
Mean	6.31	4.79	7.32	5.56	7.48	5.69	6.30	4.79	4.68	3.56	3.27	2.48	34.74	26.40

19. TRANSPIRATION

Nearly 99 percent of the water absorbed by a plant is discharged into the atmosphere as water vapor. The amount of water absorbed and thus the amount vaporized depends on the plant characteristics, air temperature, sunshine, wind, topography and numerous other factors. Transpiration rates experienced at one location may not occur at a nearby locale. A procedure to determine the consumptive use of water by various types of plant life has been developed by G. H. Hargreaves (26). The determination of consumptive needs of plant life by this method is dependent on temperatures, evaporation, humidity, and the type and general location of the plant growth. This relationship is given as:

$$T = kd\ (0.38 - 0.0038h)\ (t-32) - E$$

where:

- T = Transpiration loss - inches
- k = Monthly consumptive use coefficient
- d = Monthly daytime coefficient
- h = Mean monthly noon relative humidity - percent
- t = Mean monthly temperature - ^{o}F
- E = Lake surface water evaporation - inches

As temperatures increase, the consumptive needs of plant life increase. Inspection of maximum recorded temperatures in the basin, Table C-7, p. C-28, Appendix C - Climate, indicates a fairly uniform recorded maximum temperature throughout the basin with the exception of the far west section. It is considered reasonable to assume that a high temperature sequence experienced at one location within the basin could apply throughout the basin. Maximum recorded temperatures since 1949 at Lansing and Grand Rapids for the 3-month period of June through August, when consumptive needs of plants are greatest, were in 1955. The average temperature for this period was 73.2^{o}F. The normal average temperature for this period is 69.0^{o}F. Average monthly temperatures in 1955 for Lansing and Grand Rapids are shown on table D-11.

Table D-11

1955 TEMPERATURES AT EAST LANSING AND GRAND RAPIDS

EAST LANSING

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
24.6	26.6	34.3	54.5	61.0	(1) 67.7	77.8	75.4	63.9	54.6	35.3	25.7

GRAND RAPIDS

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
24.2	25.2	33.1	52.8	59.6	66.4	76.9	75.1	62.2	53.9	35.3	25.5

(1) Warmest three-month period of June through August since 1949.

Relative humidity records available for the Lansing and Grand Rapids areas indicate a fairly uniform relative humidity throughout the basin. It is considered reasonable to assume that the monthly average relative humidities recorded at one locale within the basin could apply throughout the basin. The average monthly noonday relative humidities in 1955 at Grand Rapids are presented in table D-12.

Table D-12

(1) 1955 RELATIVE HUMIDITY AT GRAND RAPIDS

Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.
61	48	48	48	53	45	49	57	57

(1) Average monthly noon relative humidity.

Note - 1955 Relative humidities not recorded at East Lansing.

Monthly consumptive use coefficients for various plant forms are presented in table D-13.

Table D-13

MONTHLY CONSUMPTIVE USE COEFFICIENTS (27)

Crop	Mar.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.
Hydrophytes	-	0.32	1.34	1.42	1.40	1.44	0.51	-	-
Forage	0.50	0.81	0.64	0.77	0.83	0.76	0.70	0.44	0.41
Trees	0.14	0.45	0.49	0.74	0.71	0.55	0.43	0.36	-

Although the consumptive use of water by trees, forage, and hydrophytes vary each month, it is considered practical to apply the maximum monthly consumptive rate of either the hydrophyte, tree, or forage crops, whichever is greatest. Deciduous tree root systems typical of the trees existing in the basin have been measured to extend laterally to a distance equal to the depth the root system penetrates. Root systems of these plants normally reach depths of from 3 to 5 feet. It is noted that furrows that have been constructed for irrigative forage crops have been spaced from 3 to 4 feet apart. Hydrophyte growths in the Grand River basin lakes have been observed in water depths of 8 feet. An average shore lien or bank development could be estimated by the proportionate distribution of the various plant growths. The high proportion of organic sediment promotes this type of growth. The location of the basin in the middle latitudes results in a large variation in hours between the onset of evapotranspiration during the morning and its termination in the evening for the various months. Monthly daytime coefficients are presented in table D-14.

Table D-14

MONTHLY DAYTIME COEFFICIENTS (27)

North Latitude Degree	J	F	M	A	M	J	J	A	S	O	N	D
40	0.81	0.81	1.00	1.08	1.20	1.21	1.23	1.14	1.01	0.93	0.81	0.78
45	0.77	0.79	0.99	1.09	1.24	1.26	1.27	1.17	1.01	0.91	0.77	0.74

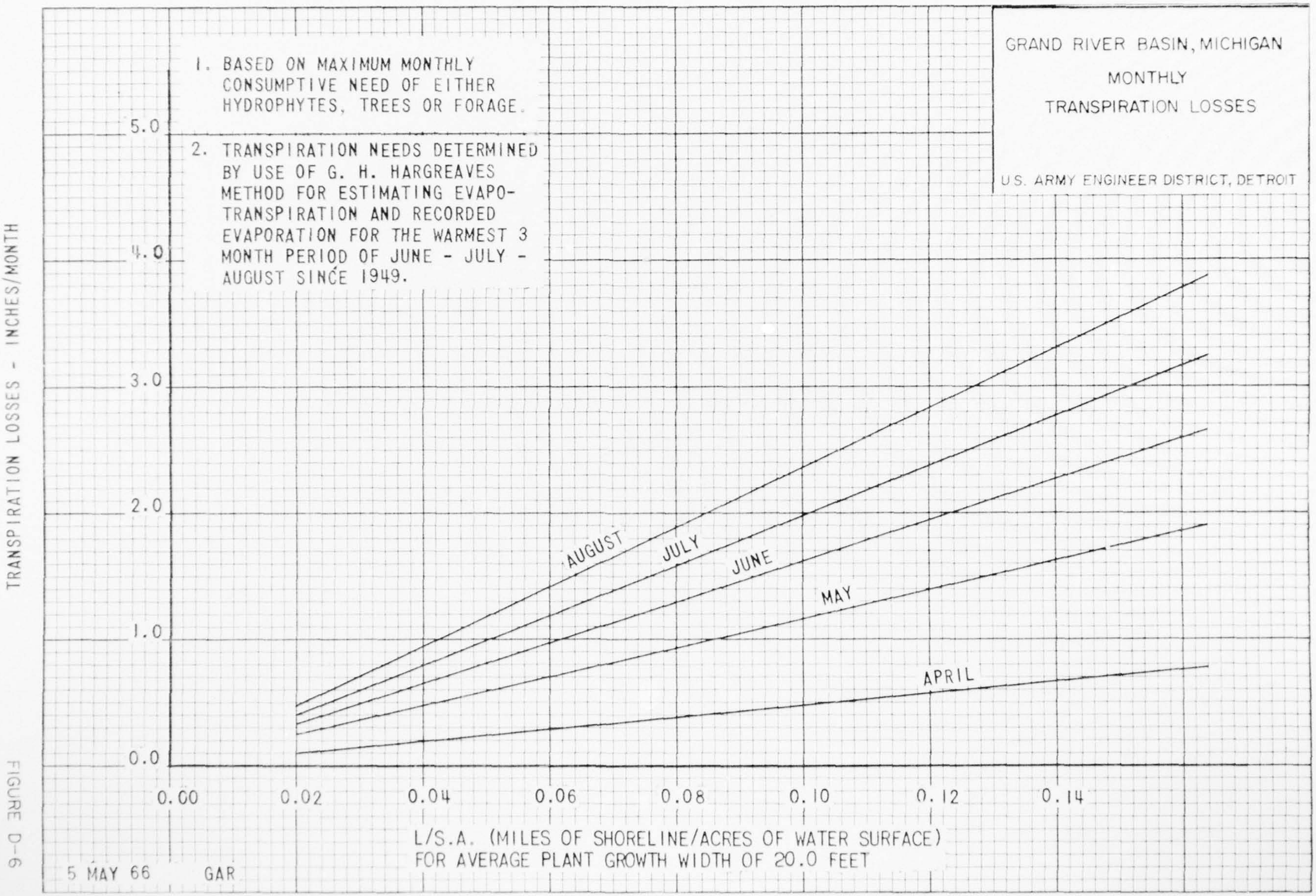

GRAND RIVER BASIN, MICHIGAN
MONTHLY
TRANSPIRATION LOSSES
U.S. ARMY ENGINEER DISTRICT, DETROIT
1. BASED ON MAXIMUM MONTHLY CONSUMPTIVE NEED OF EITHER HYDROPHYTES, TREES OR FORAGE.
2. TRANSPIRATION NEEDS DETERMINED BY USE OF G. H. HARGREAVES METHOD FOR ESTIMATING EVAPO-TRANSPIRATION AND RECORDED EVAPORATION FOR THE WARMEST 3 MONTH PERIOD OF JUNE - JULY - AUGUST SINCE 1949.
AUGUST
JULY
JUNE
MAY
APRIL
TRANSPIRATION LOSSES - INCHES/MONTH
5.0
4.0
3.0
2.0
1.0
0.0
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
L/S.A. (MILES OF SHORELINE/ACRES OF WATER SURFACE)
FOR AVERAGE PLANT GROWTH WIDTH OF 20.0 FEET
5 MAY 66
GAR

FIGURE D-6

Based on this information, a relationship is developed whereby reductions in water surface stages through transpiration losses can be estimated. This relationship provides an estimate of the monthly water surface drawdown from a composite plant growth that averages 20 feet in width for any given water surface area and length of shore or bank. Utilization of this relationship for other widths of plant growth can be accomplished by proportional adjustments. This relationship is shown as figure D-6.

20. POST PROJECT EFFECTS

In addition to reservoir losses through surface water evaporation post project effects are considered. These effects compensate reservoir losses and reflect the change in infiltration during pre-project and post project conditions. During normal pre-project conditions, considerable amounts of rainfall infiltrate the ground. During post project conditions practically none of the rainfall infiltrates the reservoir area. Post-project conditions would add to the reservoir water an amount equal to that lost through infiltration during pre-project conditions. The total rainfall amount is not added to the reservoir since the amount of post-project runoff remains to be considered in the inflow hydrograph. Average monthly infiltration percents have been determined from recorded rainfall and calculated runoff amounts for various locations within the basin. These data are shown on table D-15.

The minimum recorded precipitation for a four-month period of May through August within the basin occurred in 1930. A calculated average of 7.03 inches of precipitation occurred during this period for the entire basin. The normal average precipitation for this period is 12.65 inches. Inspection of rainfall records (29) from a 25 square mile watershed within the basin heavily populated with rain gages indicates that over an extended period of weeks, the amount of rainfall experienced within an area will be fairly uniform. Thus, it appears reasonable to assume that computed average monthly precipitaion amounts are uniform over a reservoir.

TABLE D-15

POST PROJECT CONDITIONS
RESERVOIR LOSSES

Station	% Basin Controlled	Precipitation for 1930 April inches	May inches	June inches	July inches	Aug inches	Sept inches	Oct inches
Alma	6.3	1.39	2.07	1.93	0.51	0.74	1.67	1.81
Grand Haven	5.5	2.34	1.61	1.74	0.82	0.43	1.28	2.37
Grand Rapids	10.5	2.07	2.39	2.66	0.56	0.40	1.48	2.27
Greenville	13.5	-	3.08	3.20	0.50	0.49	1.27	2.34
Charlotte	7.5	1.98	4.10	3.63	0.58	0.22	1.12	1.45
Hastings	7.8	1.47	4.02	2.80	0.43	0.54	3.11	0.96
Jackson	10.7	2.33	2.97	3.24	0.22	0.56	1.77	1.24
Lowell	9.6	2.08	3.15	2.58	0.46	0.60	1.47	1.98
Owosso	7.7	2.10	4.10	3.77	0.22	2.20	2.32	1.62
Lansing	18.4	1.97	3.36	2.79	0.50	0.18	1.42	1.00
Big Rapids	2.5	2.24	2.06	4.65	0.73	1.14	2.19	2.59
Grand Basin Avg.		2.00	3.04	2.93	0.48	0.58	1.65	1.68
% infiltration		43	62	80	87	89	90	82
Post Project Gains		0.86	1.88	2.34	0.42	0.52	1.48	1.38

SECTION V
INFILTRATION

21. GENERAL

Infiltration is the amount of downward flow of water through the soil surface as a result of precipitation and is expressed in inches per hour. During a storm, the initial infiltration rate, which may be as high as 10 inches per hour in the summer for sandy-loam grassland, can rapidly diminish to a constant rate of about 0.2 inches per hour. This rapid decrease in soil permeability is due to compaction of surface by rain impact, blocking of soil pores by fine sediment, and swelling of clays and colloids, thus reducing pore size. It is evident that these effects depend on the degree of vegetal cover, the energy of the rainfall impact, and the nature of the soil to resist the disintegrating forces (30). The initial infiltration rate also varies a great deal. Some of the factors affecting the infiltration rate are soil type and structure, amount of organic material in the soil, type of vegetal cover, biotic activity, temperature, history of land use, and soil moisture conditions (7). In general, the average infiltration rate for the Grand River basin is 0.10 inches per hour during the dormant winter and early spring months, but may range from 0.04 to 0.19 inches per hour, depending upon the influencing factors. As biological activity and evaporation increase later in the spring and summer months, the infiltration rate rises rapidly to a maximum in August. The average for this period is .80 inches per hour and ranges from .80 to 1.40 inches per hour or more. Infiltration studies are described in the following paragraphs (31).

22. DERIVATION AND EXPRESSION OF INFILTRATION DATA

Infiltration data are usually expressed as infiltration curves or infiltration indices. These are used to estimate runoff from a storm by determining the net rain which exceeds the infiltration rate. The infiltration curves, of which there are three kinds, are

more precise and rational than the infiltration indices, because they take into account the curvilinear relationship of infiltration with time. It is more common to use infiltration indices than to use infiltration curves for multiple complex drainage basins. Infiltration indices are largely empirical and are ordinarily computed from correlation of rainfall data runoff hydrographs, and physical characteristics. They vary in complexity of derivation depending upon the amount of detail used in analyzing the runoff process and the methods of rainfall disposal. The simplest is the Ø index; this is equal to the inches of rainfall per hour less the surface runoff in inches per hour. Included in the Ø index are depression storage losses along with infiltration occurring after the end of excess rainfall. The Ø index may be simplified further by including interception loss, in which case Ø index becomes a storm-loss index. The storm-loss index rate divides the gross-rainfall hydrograph into two parts, net rain and storm-loss.

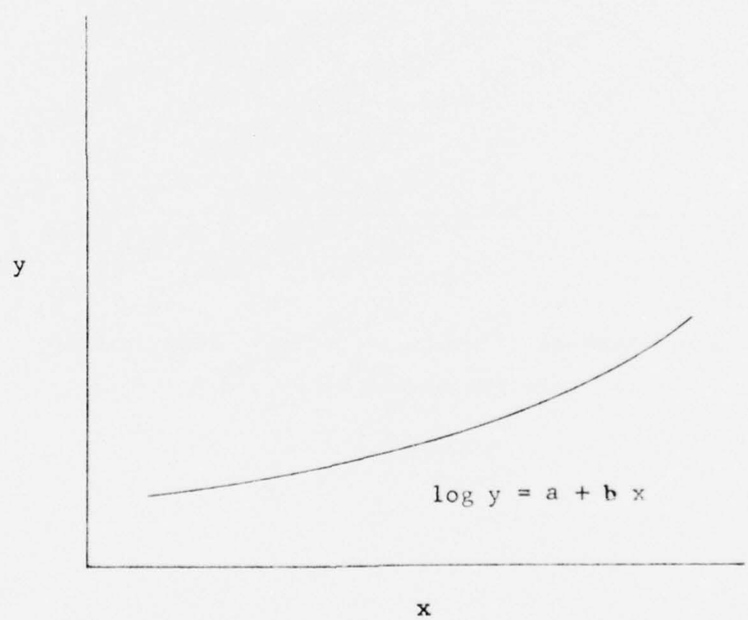
23. METHOD USED FOR GRAND RIVER BASIN

For the Grand River basin, the storm-loss index method was used. A more detailed analysis was not warranted because of insufficient data available to determine infiltration capacities. In determining the storm-loss index, hydrographs from 30 ideal storms that occurred in every month but September and December were analyzed for several sub-basins. Out of 57 hydrographs analyzed, the resulting data from only 38 hydrographs representing 25 different storms were reliable enough to be used for correlation. The procedure was, first, to determine the amount of direct surface runoff, second, to determine the representative rainfall for that drainage area, and third, to separate the gross-rainfall hydrograph, or hyetograph, into storm-loss and net rain. The net rain is equal to the direct surface runoff and does not include subsurface, groundwater, or antecedent storm flow. Subsurface storm flow is that portion which flows part of the distance underground near the surface and reaches the stream fairly rapidly without ever joining the main ground water body. In addition to the normal data associated with the derivation of the storm-loss index rate, it was necessary to know for correlation purposes, the week of the year and the soil moisture conditions at the time of each storm.

24. CORRELATION OF DATA

a. General. Various methods of correlation were attempted using different combinations of factors. The best correlation was obtained by using multiple linear regression by correlating the log of the storm-loss index rate against the logs of the week of the calendar year, the total rainfall which occurred during the period of excessive precipitation, duration of excessive precipitation, and antecedent precipitation index.

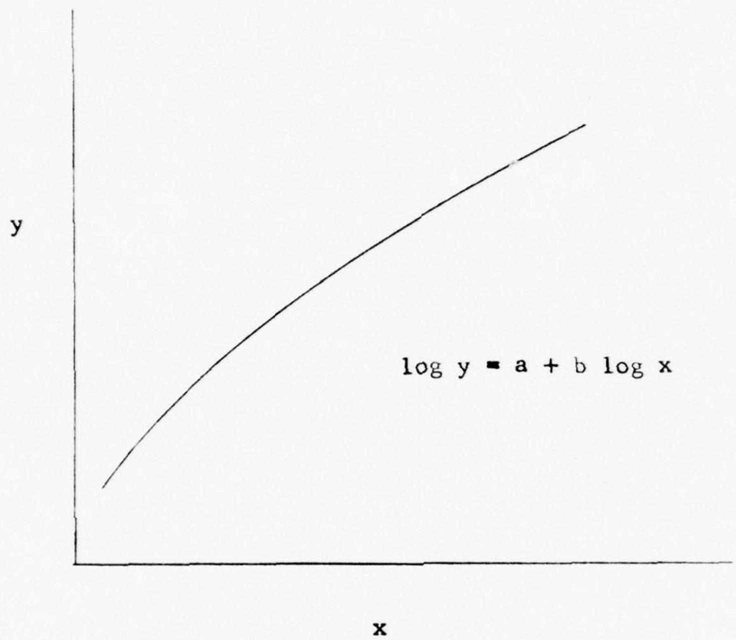
b. Basis for development. During the winter and early spring months, the relationship between storm-loss index rate and week has a different characteristic curve when plotted than for the later spring and summer months. The first curve, figure D-7, is best expressed in the form of equation $\log y = a + b\,x$ with a positive slope shown as follows, where y is the storm loss index and x is the week.



Storm-Loss vs. Week Characteristic Relationship
Winter-Early Spring Period

Figure D-7

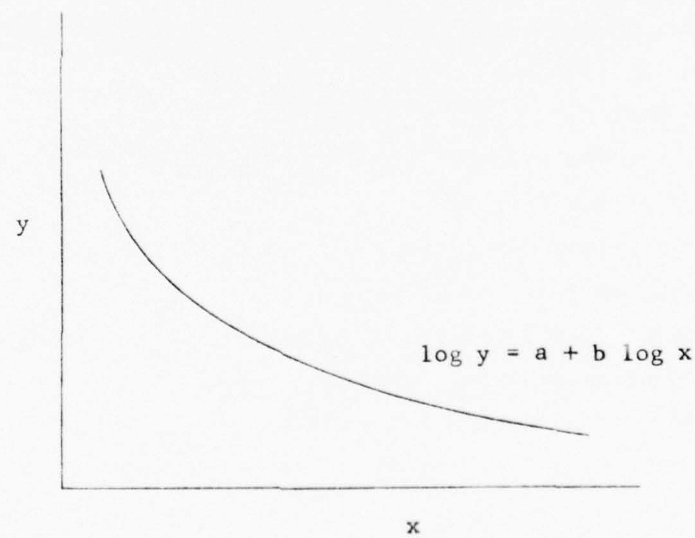
The characteristic curve shown on figure D-8 for the late spring and summer months is best expressed by the equation $\log y = a + b \log x$ with a positive slope.



Storm-Loss vs. Week Characteristic Relationship
Late Spring-Summer Period

Figure D-8

For this reason, the data were separated into these two periods, and two separate relationships were developed. No relationship was developed for the 33rd through 2nd weeks because there is no danger of floods during this period. Table D-16 lists the storm data used to develop the 2nd - 20th week relation, and table D-17 lists the storm data for the 21st - 32nd week relation. The data for the 19th and 20th week of May were used in developing both relationships. In case of an early or late spring, the actual week could be decreased or increased as necessary to better indicate temperature and soil-complex conditions that actually exist. Correlation with the total precipitation falling during the period of excess rainfall, the duration of excess rainfall, and the antecedent precipitation index all follow the same basic relationship expressed by the equation $\log y = a + b \log x$ with a negative slope, as shown on figure D-9, where y is the storm-loss index rate and x is one of the three independent factors.



Storm-Loss vs. Rainfall Excess, Duration, and Antecedent Precipitation Index Characteristic Relationship

Figure D-9

However, the correlation coefficient indicated that the relationship of storm-loss with precipitation is positive, that is, the more precipitation, the higher the storm-loss rate. This seemingly contradictory relationship is explained by noting that the greater magnitude storms were usually of shorter duration which resulted in the higher storm-loss rate. This indicates that the greater intensity rainfall is less of a factor than the decrease in duration which allows less time for the soil to approach saturation. It is significant to note that the variation in any of the independent variables cannot be considered without realizing its dependency on the other variables. Thus, it is only correct to say that an increase in precipitation would normally be accompanied by an increase in the duration of that precipitation, and thus a possible decrease in the storm-loss rate.

c. Correlation relationships. Following are the formulas developed which provided the most satisfactory results determining storm-loss index rates:

2nd - 20th Week

$$\log(100\,L) = .5298 + .0187 \times W + .8843 \log(100\,P_e) - .9235 \log T_e - .5014 \log(100\,API)$$

21st - 32nd Week

$$\log(100\,L) = .9405 + 1.5180 \log W + .7406 \log(100\,P_e) - 1.0267 \log T_e - .3721 \log(100\,API)$$

where L = storm-loss index rate

W = week of year

P_e = total precipitation during excess rainfall period, inches.

T_e = duration of excess rainfall in hours

API = antecedent precipitation index

Tables D-16 and D-17 show how the computed values compare with the observed values for the two periods. The derived storm-loss index rates are assumed representative throughout the Basin. Most of the Grand River basin is covered by podzolic soils derived mainly from glacial till and devoted primarily to agriculture (32/12). It was assumed that all the major sub-basins would have the same infiltration characteristics

Table D-16

STORM DATA USED TO DERIVE CORRELATION FORMULA FOR 2ND-20TH WEEK

Correlation formula: $\text{Log}(100\ L) = .5298 + .0187\ W + .8843\ \text{Log}(100\ P_e) - .9235\ \text{Log}\ T_e - .5014\ \text{Log}(100\ \text{API})$

Storm	Basin	Week	Total Precip. inches	Excessive Precip. (P_e) inches	Total Duration hours	Duration of Rainfall (Hrs.)T_e	Runoff inches	API	Storm Loss Index Rate(L) Actual in./hr.	Storm Loss Index Rate(L) Computed in./hr.
1/12/60	Rogue (1)	2	1.47	.68	21	6	.29	.31	.07	.05
"	Flat	2	1.20	.81	23	10	.17	.18	.06	.05
"	Quaker	2	1.34	1.02	24	14	.45	.21	.04	.04
"	Deer	2	1.34	1.05	24	14	.47	.24	.04	.04
2/15/54	Red Cedar	7	2.40	1.51	22	5	.54	.28	.19	.17
2/20/53	Rogue (1)	8	1.24	1.17	5	3	.33	.37	.28	.19
"	Red Cedar	8	.33	.22	4	1	.04	.15	.18	.19
"	Flat	8	.55	.39	6	2	.22	.31	.09	.12
3/19/48	Thornapple	12	2.60	2.38	14	8	1.19	.44	.15	.16
"	Orchard	12	2.24	1.84	15	7	.63	.43	.17	.14
"	Red Cedar	12	2.72	2.37	15	8	1.26	.40	.14	.17
3/25/54	Red Cedar	12	1.58	.99	12	3	.47	.63	.17	.15
3/31/49	Red Cedar	13	1.49	.96	18	5	.46	.58	.10	.10
4/5/47	Maple	14	2.00	1.60	17	10	1.08	1.23	.05	.06
"	Thornapple	14	2.65	2.26	15	11	1.41	.93	.08	.08
"	Red Cedar	14	2.46	2.35	18	8	1.68	1.10	.08	.11
"	Orchard	14	2.70	2.35	14	8	1.39	.88	.12	.12
4/24/61	Sloan	17	.75	.50	9	4	.32	1.25	.05	.06
5/5/56	Rogue(1)	18	2.45	2.07	14	8	.51	1.51	.20	.10
"	Sloan	18	.62	.42	9	3	.25	1.84	.06	.05
5/9/56	Rogue	19	1.27	1.05	13	7	.39	2.29	.09	.05
"	Sloan	19	2.02	1.59	16	8	1.16	1.69	.05	.08
"	Deer	19	1.84	1.48	16	8	.85	1.67	.08	.07
"	Red Cedar	19	1.68	1.33	17	9	.67	1.67	.07	.06
5/12,13/56	Deer	19	1.56	1.49	5	3	.94	2.68	.18	.14
"	Sloan	19	1.16	1.11	5	3	.79	2.67	.11	.11
5/10/63	Deer	19	.95	.67	8	4	.23	.96	.11	.09
5/19/57	Sloan	20	1.73	1.39	26	12	.75	1.47	.05	.05

(1) Rogue River data not used in deriving formula. Storm-loss index rates for the Rogue basin are 1.32, 2.01, 1.84 and 1.47, or an average of 1.66 times greater than computed value. Computed value using formula should be multiplied by 1.66 for Rogue basin.

with the data from the various sub-basins therefore combined for the determination of the storm-loss index rate characteristics. The only exception is the Rogue River which drains mostly sandy soils located in northern Kent County and beyond (8). This zone would naturally be expected to have a higher infiltration rate, and this is borne out by the results of the storm-loss analysis. To improve the correlation for the rest of the Grand River basin, data from the Rogue River basin were excluded. The method for determining the storm-loss index rate for the Rogue River basin is explained in footnote 1 on tables D-16 and D-17. When applying these relationships, it is important that the same method of analysis for the antecedent precipitation index, precipitation data, and hydrographs be used as were used in the development of the derived relationships.

Table D-17

STORM DATA USED TO DERIVE CORRELATION FORMULA FOR 21ST-32ND WEEK

Correlation formula. $\text{Log } (100 \text{ L}) = -.9405 + 1.5180 \text{ Log W} + .7406 \text{ Log } (100 \text{ P}_e) - 1.0267 \text{ Log T}_e - .3721 \text{ Log } (100 \text{ API})$

Storm	Basin	Week	Total Precip. inches	Excessive Precip. (P_e) inches	Total Duration hours	Duration of Rainfall (hrs.)Te	Runoff inches	API	Storm Loss Index Rate (L) Actual in./hr.	Storm Loss Index Rate (L) Computed in./hr.	Storm Loss Index Rate (L) Computed in./hr.
5/9/56	Rogue(1)	19	1.27	1.05	13	7	.39	2.29	.09	.06	.051(2)
"	Sloan	19	2.02	1.59	16	8	1.16	1.69	.05	.08	.076(2)
"	Deer	19	1.84	1.48	116	8	.85	1.37	.08	.07	.072(2)
"	Red Cedar	19	1.68	1.33	17	9	.67	1.67	.07	.06	.059(2)
5/12,13/56	Deer	19	1.56	1.49	5	3	.94	2.68	.18	.17	.141(2)
"	Sloan	19	1.16	1.11	5	3	.79	2.67	.11	.13	.109(2)
5/10/63	Deer	19	.95	.67	8	4	.23	.96	.11	.10	.089(2)
5/19/57	Sloan	20	1.73	1.39	26	12	.75	1.47	.05	.05	.052(2)
5/31/58	Sloan	22	1.27	1.24	2	1	.02	.23	1.22	1.38	
6/9/63	Deer	23	1.16	1.06	2	1	.16	.88	.90	.80	
	Red Cedar	23	1.97	1.16	3	1	.15	.88	1.01	.93	
"	Flat	23	.75	.75	1	1	.04	.40	.71	.92	
"	Rogue(1)	23	.82	.71	3	1	.11	.78	.60	.62	
7/3/58	Sloan	27	2.13	.54	13	1	.03	1.59	.51	.50	
7/4/58	Sloan	27	.88	.77	3	2	.08	2.15	.35	.28	
7/6/58	Sloan	27	.31	.21	2	1	.03	2.45	.18	.21	
7/4/57	Sloan	27	2.36	2.17	3	2	.23	.74	.97	.91	
7/8/57	Sloan	27	1.19	.69	5	1	.18	1.74	.51	.58	
7/11/57	Sloan	28	3.45	2.88	10	5	1.56	2.03	.26	.32	
7/20/59	Sloan	29	2.06	1.45	7	1	.05	.61	1.40	1.59	
7/29/59	Sloan	30	1.55	1.20	3	1	.07	1.52	1.13	1.07	
7/30/59	Sloan	31	.76	.75	2	1	.06	2.82	.69	.63	
8/9/56	Sloan	32	2.00	1.50	2	1	.17	1.33	1.33	1.46	

(1) Rogue River data not used to derive formula. Based on the storm of 6/9/63, the computed storm-loss index rate agrees with the observed rate and the formula appears applicable to the Rogue basin during the summer months. However, before 1 June, let's say, the computed value should be multiplied by 1.66 as explained in the footnote on Table 1.

(2) Computed storm-loss index rates for 19th and 20th weeks using the formula developed for the winter and first half of spring. Although the results from both formulas have the same average percent error, the formula for the winter-early spring period gives over-all lower values which would provide an added safety factor in predicting floods.

SECTION VI
RIVER STAGE AND FLOOD FORECASTING

25. STATUS

A flood forecasting service on the Grand River is maintained by the U.S. Weather Bureau. By observing upstream river stages as well as existing rainfall and snow cover on the Basin, the Bureau is able to predict flood peaks a few days in advance. The U.S. Weather Bureau Station at Lansing forecasts river stages from gages located at Williamston and East Lansing on the Red Cedar River and at Eaton Rapids, Dimondale, Lansing, and Grand Ledge on the Grand River. River stages downstream of Grand Ledge are forecasted by the U.S. Weather Bureau Station at Grand Rapids from the previously cited gages in addition to gages at Portland, Ionia and Grand Rapids on the Grand River. Data are obtained from daily readings which in turn are telephoned to the Lansing or Grand Rapids Station. Flood warnings are issued over radio and television, through local newspapers, and to all emergency agencies to give time for evacuation of goods and personnel and to prepare for disaster operations in the event of a serious flood. Periods of normal and low flows are not forecasted.

26. FUTURE REQUIREMENTS

Recent technical advances in communication and recording devices provide instantaneous readings of measured phenomena such as water surface levels, rainfall amounts, snow amounts, temperatures, and dissolved oxygen (D.O.) content. These devices are referred to as Telemark gages. Measured quantities are transmitted by telephone communication. Telemark stream gages have recently been installed on the Red Cedar River at East Lansing, and on the Grand River at Lansing and Grand Rapids. Inclusion of reservoir sites in the Basin will require an accurate forecasting system and a concise reporting network for the efficient and safe operation of the reservoirs. Installation of rainfall, temperature, and snow Telemark gages in reservoir headwater areas will be a valuable aid in the efficient operation of the reservoirs. Installation of D.O. Telemark gages at critical downstream locations will provide valuable

assistance in determining reservoir releases during low flow periods. The entire network of Telemark gages and weather data will be centralized such that the operation of the reservoirs will be efficient.

SECTION VII

FLUVIAL SEDIMENT INVESTIGATIONS

27. FLUVIAL SEDIMENT

Sedimentation of reservoirs in the Grand River Basin was studied at three existing reservoirs to provide design criteria for future reservoir projects. By (36) studying the sedimentation that has occurred in the existing reservoirs, it was anticipated that sedimentation in future reservoirs could be estimated and designs modified accordingly. All the significant reservoirs in the Basin were observed and three were found that approximated the conditions found throughout the Basin. The reservoirs studied were the County Farm Reservoir near Greenville in Montcalm County, the Nashville Reservoir in Nashville in Barry County, and the Smithville Reservoir near Eaton Rapids in Eaton County. These reservoirs shown on Plate D-28 were surveyed to determine the nature, size, composition, amount, and source of the sediment found in the reservoirs. Bottom samples were taken and analyzed to determine the amount of organic material, specific gravity, dry weight, and grain size gradations. Table D-18 is a summary chart showing the basic information obtained from the field surveys of three of the existing reservoirs in the Grand River Basin. The amount of storage lost ranged from 15 percent in the Smithville Reservoir to 45 percent in the Nashville Reservoir. Both of these reservoirs have been in existence a little less than one hundred years. The County Farm Reservoir has been in existence about forty years and it has had a storage loss of 38 percent. The factors that have resulted in the nearly one percent annual storage loss at the County Farm Reservoir are; its (35) higher trap efficiency and the dense vegetation growth in the reservoir which results in a large amount of organic sediment. The average depth of water in the County Farm Reservoir is 7.5 feet which results in conditions which have contributed to lush vegetation growth and results in the deposition of large amounts of organic sediment. Figure D-10 is a graph showing the relation between depth of water and the amount of organic material in the sediment. Soil

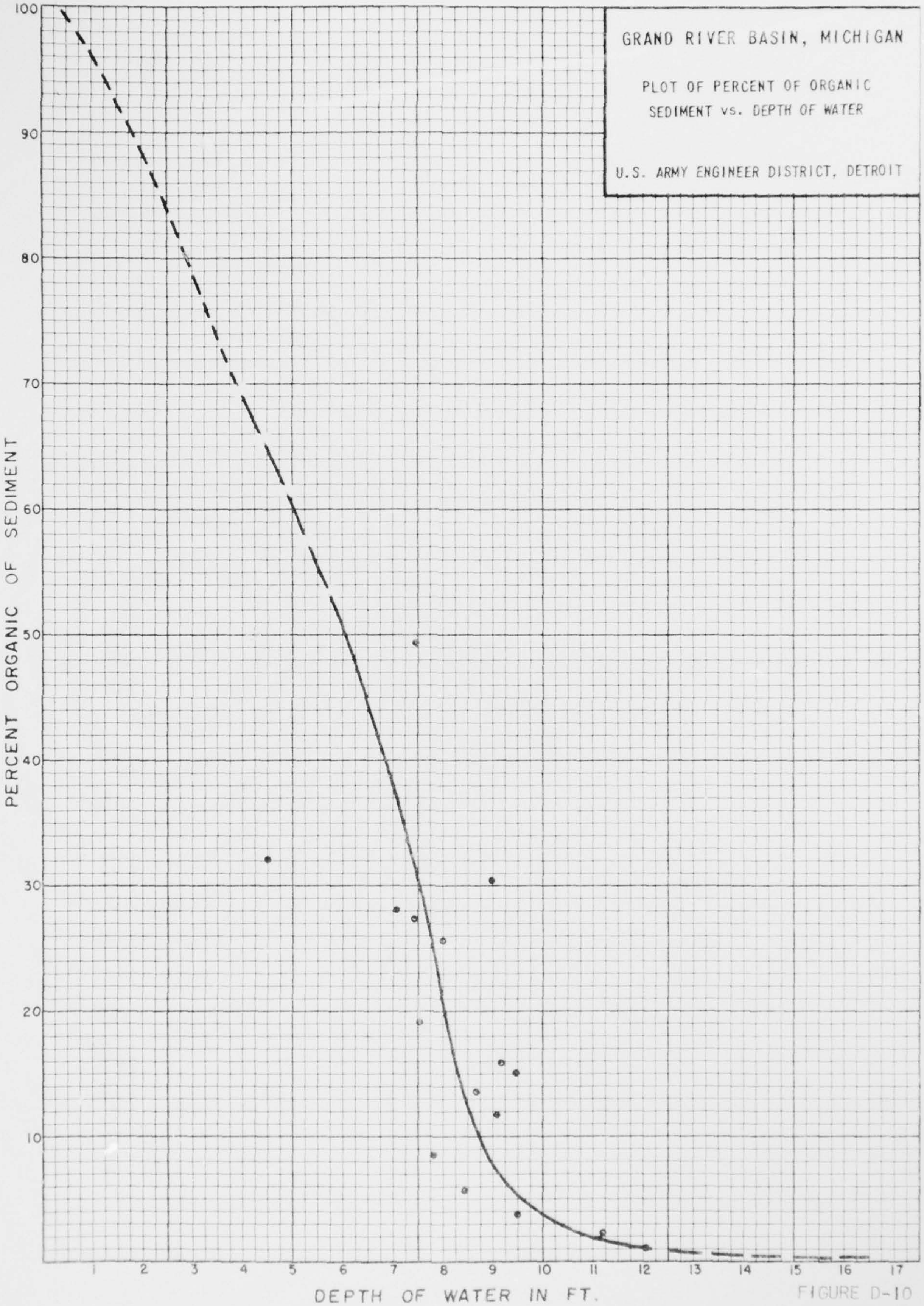

GRAND RIVER BASIN, MICHIGAN
PLOT OF PERCENT OF ORGANIC SEDIMENT vs. DEPTH OF WATER
U.S. ARMY ENGINEER DISTRICT, DETROIT
PERCENT ORGANIC OF SEDIMENT
100
90
80
70
60
50
40
30
20
10
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
DEPTH OF WATER IN FT.

FIGURE D-10

TABLE D-18
SUMMARY OF DATA ON EXISTING RESERVOIRS

	County Farm	Smithville	Nashville
Age of Reservoir	40 years	91 years	96 years
Drainage Area	35 sq. mi.	652 sq. mi.	200 sq. mi.
Reservoir Water Surf. Area	9.7 acres	61.0 acres	65.0 acres
Storage Capacity			
a. Original	71.5 AF	464.9 AF	351.2 AF
b. Present	44.1 AF	394.9 AF	192.6 AF
Capacity per $mi.^2$ of drainage area			
a. Original	2.04	.71	1.76
b. Present	1.26	.54	.96
Total Sedimentation	27.4 AF	70.0 AF	158.6 AF
Average annual accumulation			
a. From entire drainage area	.69 AF	.77 AF	1.65 AF
b. Per square mile of D.A.	.02 AF	.0012 AF	.0083 AF
Storage Loss	38.3%	15.1%	45.2%
Organic sediment by percent	28.8%	14.4%	15.7%
Average annual accumulation of organic sed. per acre of reservoir surface area	.02	.002	.004

samples were taken in the drainage areas of the reservoirs studied and analyzed to determine the percent of organic material. As illustrated in Figure D-10, when the depth of water exceeds eight feet, the percentage of organic material sharply declines until the water depth exceeds twelve feet and then the percent organic of the bottom sediment becomes very low and approximates the percent of organic material found in the topsoil in the reservoir drainage area. The amount of organic material in the topsoil was found to be between two and four percent. Therefore, nearly all the organic sediment has its origin in the reservoir itself. The depth and quality of water in the reservoir has a decisive influence on the amount of vegetation growth.

28. SEDIMENT LOAD

The amount of sediment that a stream can carry is dependent on many factors that often vary considerably from one stream to another. Stream velocity is the principal factor in the amount of suspended and bed load sediment that a stream can transport. Any change in stream flow velocity resulting in lowering the rate of flow will cause deposition of the heavier particles. An increased rate of flow will increase the streams competence to transport sediment, and could result in localized bank or channel erosion. The amount of sediment transported as bed load should be less than 10 percent of the total sediment transported in the Grand River Basin. The topography of the Basin is flat to undulating and about seventy percent of the land is used for agricultural purposes. Soils in the Basin have a relatively good resistance to erosion. However, erosion is influenced by topography and soil loss on a 10 percent slope would normally be 2.5 times that on a 5 percent slope. When highway construction and urban development result in large areas being without their natural vegetation, large quantities of material may be eroded in the relatively short time that the land is bare. The sediment load of the streams affected may be increased many times, and the increased load may persist for several years before the material is transported through the drainage system.

29. SEDIMENT CONCENTRATION

There has been very little work done on determining the amount of suspended sediment in the streams of the Grand River Basin. The United States Geological Survey has conducted suspended sediment surveys at various locations, but they have not sampled continuously at any station for a sufficient length of time to give results that could be used to predict the amount of sediment carried by the streams in the Basin. The suspended sediment study, done about 1958 in the Deer and Sloan Basins (37) which are located in the Grand River Basin, indicated that the suspended sediment concentration averaged about 300 p.p.m. Based on studies conducted in similar basins elsewhere, the average suspended sediment concentration in the Grand River Basin would be about 300 to 500 p.p.m. As sediment concentration and load can vary greatly in a stream from day to day and from storm to storm, frequent measurements over a period of many years are often required to define the average annual sediment yield from a basin. Records of only a few years duration can be useful in predicting the long-term annual sediment yield.

30. NATURE, SIZE AND SOURCE OF SEDIMENT

The predominate soils types in the Basin are the silty sandy loams, which when eroded, result in silty sediments. From fifteen to thirty percent of the sediments were found to be black organic silt by laboratory testing. The organic sediments result from vegetation in the reservoir. The shallow reservoirs in the basin have a great deal of vegetation, which causes the reservoirs to lose some of their recreation value. Lush aquatic plant growth makes boating difficult and in some cases impossible. Fishing and swimming are also severely impaired. The vegetation not only contributes to the sediment deposited, but also filters the suspended sediment; therefore, the trap efficiency of the reservoir is increased. The vegetation is subject to annual die off and the decayed matter is deposited on the bottom and enriches the sediment already deposited to further encourage plant growth and the organic sediment tends to accumulate at an ever increasing rate through time. In the present reservoirs in the Basin, the water flows through

well defined channels. These channels contain the lesser amounts of sediment. Even after construction of the reservoir impoundments, most flows follow the natural channels submerged within the impoundments. Since there is very low flow outside the channels, the greatest accumulation of sediment is here. The areas of low flow in the reservoirs also support lush vegetation in the shallow reservoirs. The proposed reservoirs have a much larger surface area than the existing reservoirs of the Basin; therefore the proposed reservoirs would trap more organic sediment. The proposed reservoirs would also have a trap efficiency of nearly 100 percent which is much greater than the trap efficiency of the existing reservoirs. Nearly all the suspended sediment carried into the proposed reservoirs would be trapped in the reservoir due to higher trap efficiency. By using the soil erosion rates that have been developed by the U.S. Department of Agriculture, the amount of sediment supplied to a particular reservoir can be rather accurately determined. Knowing the amount of sediment entrained and the trap efficiency, the amount of sediment deposited can be accurately determined.

31. SEDIMENT ACCUMULATION

The sediment that accumulates in a reservoir depends on several factors, which include the size, shape and depth of water in the reservoir, and the trap efficiency of the reservoir. Using the ratio of capacity to annual inflow of the reservoirs studied in the Grand River Basin, the trap efficiency of the existing reservoirs is less than 10 percent. Organic material is a major part of the sediment in the reservoirs. Temperature, sunlight, size, shape and slope of the reservoir basin, good water quality, clarity, nutrients and dissolved oxygen influence vegetation growth in reservoirs. The water around the edges of the reservoirs should be as deep as possible to minimize the amount of aquatic growth in these areas. The banks of the reservoirs should also be as steep as stability and erosion characteristics of the banks permit. Figure D-11 shows the relationship between the percent of organic sediment and the depth of water, and the reduction of organic sediment with increasing water depth. The sediment where the

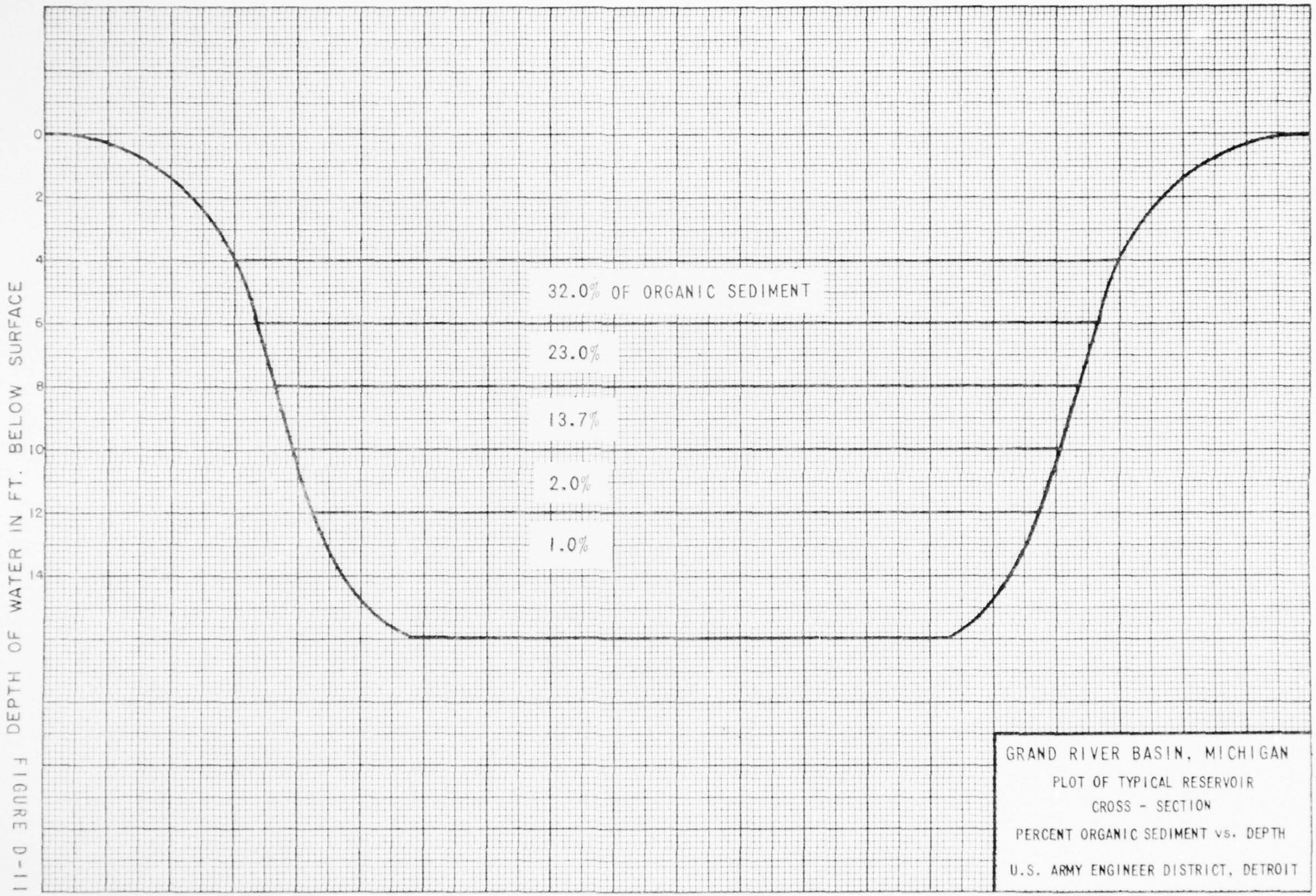

DEPTH OF WATER IN FT. BELOW SURFACE
0
2
4
6
8
10
12
14
32.0% OF ORGANIC SEDIMENT
23.0%
13.7%
2.0%
1.0%
GRAND RIVER BASIN, MICHIGAN
PLOT OF TYPICAL RESERVOIR
CROSS - SECTION
PERCENT ORGANIC SEDIMENT vs. DEPTH
U.S. ARMY ENGINEER DISTRICT, DETROIT

FIGURE D-11

water is over twelve feet deep had about the same percentage of organic material as the topsoil of the reservoir basin. Water quality should be studied in streams which flow into the proposed reservoirs to determine the amounts of suspended sediment and nutrients which will have a significant effect on the growth of vegetation in the reservoir.

Computation of the amount of storage loss by sedimentation in the proposed reservoirs must be done on an individual basis. This requires information concerning the control structures in the stream, information regarding the shape of the bottom of the reservoir, the quality of the water flowing into the reservoir, and the size and topography of the drainage basin. The average storage loss for a reservoir in the Grand River Basin is estimated to be approximately 15 percent over a period of one hundred years. However, each site must be considered individually to determine the amount of storage loss for that site.

32. TRENDS IN SEDIMENT YIELDS

The amount of fluvial sediment transported in the streams of the Grand River Basin will not change greatly in the future. Future erosion will probably remain fairly constant because the land use is not expected to undergo any great changes which would greatly affect erosion. Erosion in the Basin has so stabilized that it approximates soil accumulation. Erosion is estimated to be three to four tons per acre annually; this is a low rate of erosion. Organic sediment which is the major sediment in reservoirs can be expected to increase due to the continuing enrichment of the streams by sewage effluent and chemical fertilizers applied to agricultural lands which are partially washed into the streams of the basin. Sewage effluent is not only rich in nutrients, but it also raises the water temperature. The higher temperatures along with the nutrients result in lush growth of vegetation. There is every indication that the organic sediment deposited will at least continue at its present annual rate of about .02 acre-feet per surface area in areas of the reservoir where the depth of water is less than ten feet. Where the water depth is greater than

ten feet, the organic sediment is usually much less. Unless the present trend of enriching stream water is reversed, organic sedimentation at the reservoir sites will increase. Therefore, reduction of stream pollution, particularly the amount of nitrogen and phosphorus, will also reduce aquatic growth and organic sedimentation. Studies have determined that the annual per capita contribution of domestic sewage is 4.1 pounds of nitrogen and 1.1 pounds of soluble phosphorus. According to Sawyer* (34), the annual per capita contribution may supply sufficient nitrogen to fertilize one acre of lake water to a depth of five feet and sufficient soluble phosphorus to fertilize seven acres of lake water to a depth of five feet to such an extent that nuisance algal blooms may occur during the summer months.

33. SHEET EROSION

Sheet erosion is the loss of soil materials from the general land surface by the action of unrestricted and unchannelized runoff. Wind erosion is a special form of sheet erosion--the mechanics of the eroding action being different, but the net effect the same. Sheet erosion is accentuated where the natural landscape has been altered by the activities of man. These alterations leave the land more vulnerable to the weathering processes, and greater soil losses occur. There are a large number of variables that influence the rates of soil loss by sheet erosion. These variables are involved with the basic morphology of the various soils, the relief of the land, the degree of surface cover protection, and land management, such as tillage practices. Soil loss estimation has been put on a quantitative basis by analyses of plot data from research stations. G. W. Musgrave (38) and associates, developed the soil-decline equation which is expressed by the following relationship:

$$E = FRS^{1.35} L^{0.35} P_{30}^{1.75}$$

*Reference

Sawyer, C. N., "Fertilization of Lakes by Agricultural and Urban Drainage", Jour. N. Eng. Water Works Assn. (1944)

where E = sheet erosion, tons/year

F = soil factor, basic erosion rate in tons/year for each soil unit

R = cover factor

S = land slope in percent

L = length of land slope in feet

P_{30} = maximum 30-minute, 2-year, frequency rainfall, in inches

Another system, which is widely used in the north central states, is the Universal Soil Loss Estimation Equation. (39)

$$A = RKLSCP$$

where A = average annual soil loss in tons/acre

R = the rainfall-erosion index

K = basic soil factor

L = length of slope factor

S = steepness of slope factor

C = cropping-management factor

P = erosion control practice factor

The Musgrave equation, also known as the Northeastern States equation, was developed about 25 years ago. Another system, known as the Cornbelt States method, evolved at about the same time. The Universal Soil Loss equation has been developed within the past 10 years and it retains some of the features of the Musgrave and Cornbelt equations. Two developments of the U.S. Runoff and Soil Loss Data Laboratory, Lafayette, Indiana, contributed largely to the major improvements in soil loss prediction. They were the development of the rainfall erosion index and a method of evaluating the cropping-management factor. Tables D-19 and D-20 show comparable soil loss values in tons/acre/year computed by using the Universal Soil Loss equation. The values are for Miami silt loam in central Michigan with slope lengths that average 200 feet. Table D-19 values are for an average level of management with no mechanical practices. Table D-20 values are for an average level of management with contour farming.

TABLE D-19

Tons Soil Loss/Acre/Year	No Mechanical Practices Slope %			
Rotation	2	6	10	14
1. Continuous Corn	5.6	17.2	35.7	61.0
2. 2 year corn - 1 year small grain - 2 year meadow	1.7	5.2	10.7	18.3
3. Corn - small grain - meadow	1.2	3.8	7.9	13.4
4. Corn - small grain - 4 year meadow	0.7	2.1	4.3	7.3
5. Small grain - 4 year meadow	0.2	0.7	1.4	2.4

TABLE D-20

Tons Soil Loss/Acre/Year	With Contouring Slope %			
Rotation	2	6	10	14
1. Continuous Corn	5.4	8.6	22.0	48.8
2. 2 year corn - 1 year small grain - 2 year meadow	1.0	2.6	6.4	14.7
3. Corn - small grain - meadow	0.7	1.9	4.7	10.7
4. Corn - small grain - 4 year meadow	0.4	1.0	2.6	5.9
5. Small grain - 4 year meadow	0.1	0.3	0.9	2.0

Examination of the data on Tables D-19 and D-20 illustrate three facts about soil loss from sheet erosion: (1) soil loss increases with increasing slope, other factors remaining the same, (2) soil loss decreases with less intense cropping, and (3) mechanical practices reduce soil loss. Increased soil infiltration and permeability reduce soil loss as does shortening of slope lengths. The Miami, Nester, and associated soils in the Grand River Basin contribute a large percentage of the soil lost through sheet erosion. These soils have a higher basic erodibility factor than the very sandy soil types and they are more sloping than the Lake Plain soils. The slopes are relatively long with fairly intense cultivation. Specific quantitative data on total sheet erosion have not been developed for the Grand River Basin or its sub-basins. Soil loss from sheet erosion has been very extensive during the history of cultivation in central Michigan. Currently, soil losses range from over 50 tons per acre per year on isolated fields to a few tenths of a ton on well managed cultivated land. An average soil loss of 3 or 4 tons per acre per year is not an unreasonable estimate for the cultivated land in the Grand River Basin. Computation of gross erosion is a basic element used in predicting sediment yields at downstream points when knowledge of sediment delivery ratios are known. Computation systems for sheet erosion, as illustrated above, are available to make reliable estimates of gross erosion.

34. CHANNEL EROSION

Channel erosion refers to two types of erosion situations. One type is the extension and lateral growth of an upland channel -- commonly called a gully. The other type is the lateral erosion and collapse of the sides of the larger, lowland channels, which are floodways or are used for drainage. The extent and magnitude of these two situations in channel erosion are presented here separately. Upland gully formation begins as the result of prolonged periods of severe sheet erosion. Land in central Michigan had a layer of topsoil which had the ability to absorb much of the rainfall and to impede runoff. Prolonged cultivation depleted the effectiveness of this topsoil to

impede runoff and the topsoil was gradually eroded away by sheet erosion. Each succeeding heavy rain created more and more rills on the sloping fields. Tillage operations would obliterate the rills but a continuing depletion of the topsoil occurred. The tendency toward channel flow increased as runoff increased. The actual development of gully systems resulted from the migration of knickpoints up the channel systems. The mode of formation of knickpoints and the control of their migration up channel systems is a complex process. The uplands within the Grand River Basin went through a "cycle" of gully formation; channel erosion was very extensive on the slopes and in the upland drainageways. Much of the scar from this channel erosion has in subsequent years been smoothed by grading and by grass waterway establishment. The gully scars are still in evidence in many areas. Quantitative estimates of the amount of soil loss that results from upland channel erosion have not been made. Many acres have been damaged by channel erosion; the channels tend to accelerate the removal of runoff water laden with soil from the surrounding slopes. A recent guide (40) has been issued which may be used to evaluate the rate of headward advance of individual gully heads. Channel erosion in the lowland channels occurs as lateral cutting of the banks by erosion, undermining and collapse, and sometimes deepening of the channel. The problem exists along various reaches of channel within the Basin where stream bank cutting occurs. The problem has been noted particularly along channels lying within sandy outwash areas. Examples of this are reaches of the Upper Maple River and along Buck Creek in Kent County. The problem exists to some degree where new drainage channels are dug. The allowable tractive force procedure is a method available to analyze allowable velocities for various channel materials.

$$T = WDS$$

where T = tractive force in lbs/ft^2

W = unit weight of water (62.4 lbs/ft^2)

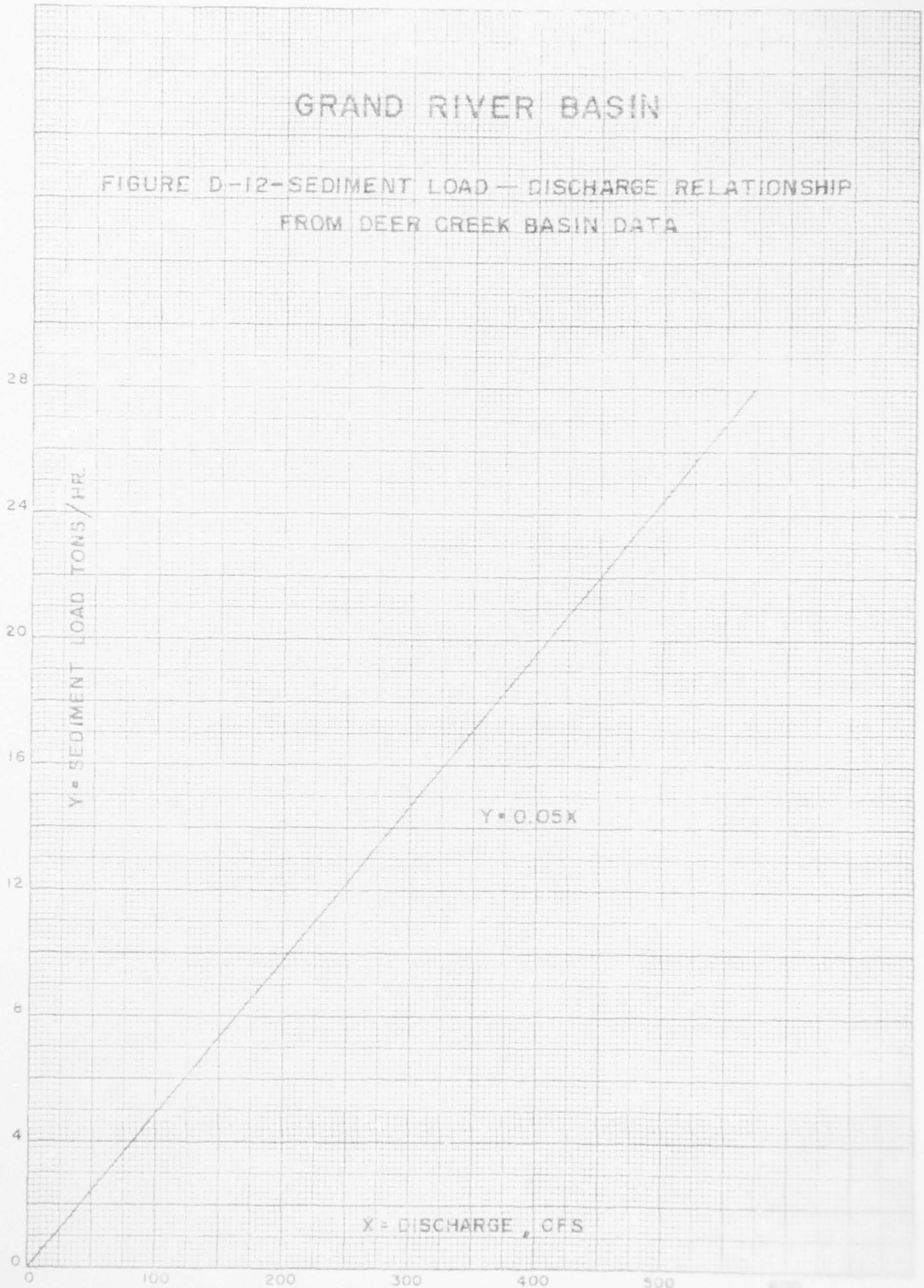
D = depth of water, feet

S = slope of energy gradient in ft/ft

Curves have been developed relating the allowable tractive force to types of channel materials. The D_{75} size (41) may be used with the coarse noncohesive channel materials. The D_{50} size (41) is used for the fine noncohesive channel materials. The plasticity index (42) is used with the cohesive channel materials.

35. SEDIMENT YIELD

Sediment yield is defined as the total sediment from all sources that is delivered to a given point in a channel system. Sheet erosion and all forms of channel erosion furnish sediments that are transported as suspended sediment or as bed load. The ratio between gross erosion and sediment yield is the sediment delivery ratio. Sediment yields are measured or estimated by different methods. The most accurate are the small research plots from which runoff and sediment are measured precisely. The next are the gauged, experimental watersheds. Reservoir sedimentation surveys and the various stream gauging systems supply reliable information for the drainage system involved. Estimates of sediment yield are generally needed on drainage systems on which no measured information is available. Sediment yields are estimated by using information available from nearby sources, generally in areas of similar physiographic and climatic conditions. This severely restricts the geographic area into which a given set of sediment yield data can be transported. Measured sediment yield data that may be used in estimating sediment yields in the Grand River Basin is very limited or is nonexistent. Data published from a study (43) of the Deer Creek Basin, subdrainage of the Red Cedar River, have been used in studying the Grand River Basin. The data include readings of the suspended sediment concentration in the runoff water at various rates of flow. The gauging was done at a point where the drainage area is 16.3 square miles. The Deer Creek Basin lies within typical mid-Michigan rolling glacial topography and contains largely Miami and associated soil types with numerous scattered areas of the sandy soil types. A linear regression was computed relating the sediment yield in tons per hour (Y) to the discharge in cfs (X). The computed regression is Y = 0.05X, shown graphically in Figure 12.


GRAND RIVER BASIN
FIGURE D-12-SEDIMENT LOAD — DISCHARGE RELATIONSHIP
FROM DEER CREEK BASIN DATA
Y = SEDIMENT LOAD TONS/HR.
Y = 0.05X
X = DISCHARGE, CFS
0
4
8
12
16
20
24
28
0
100
200
300
400
500
600

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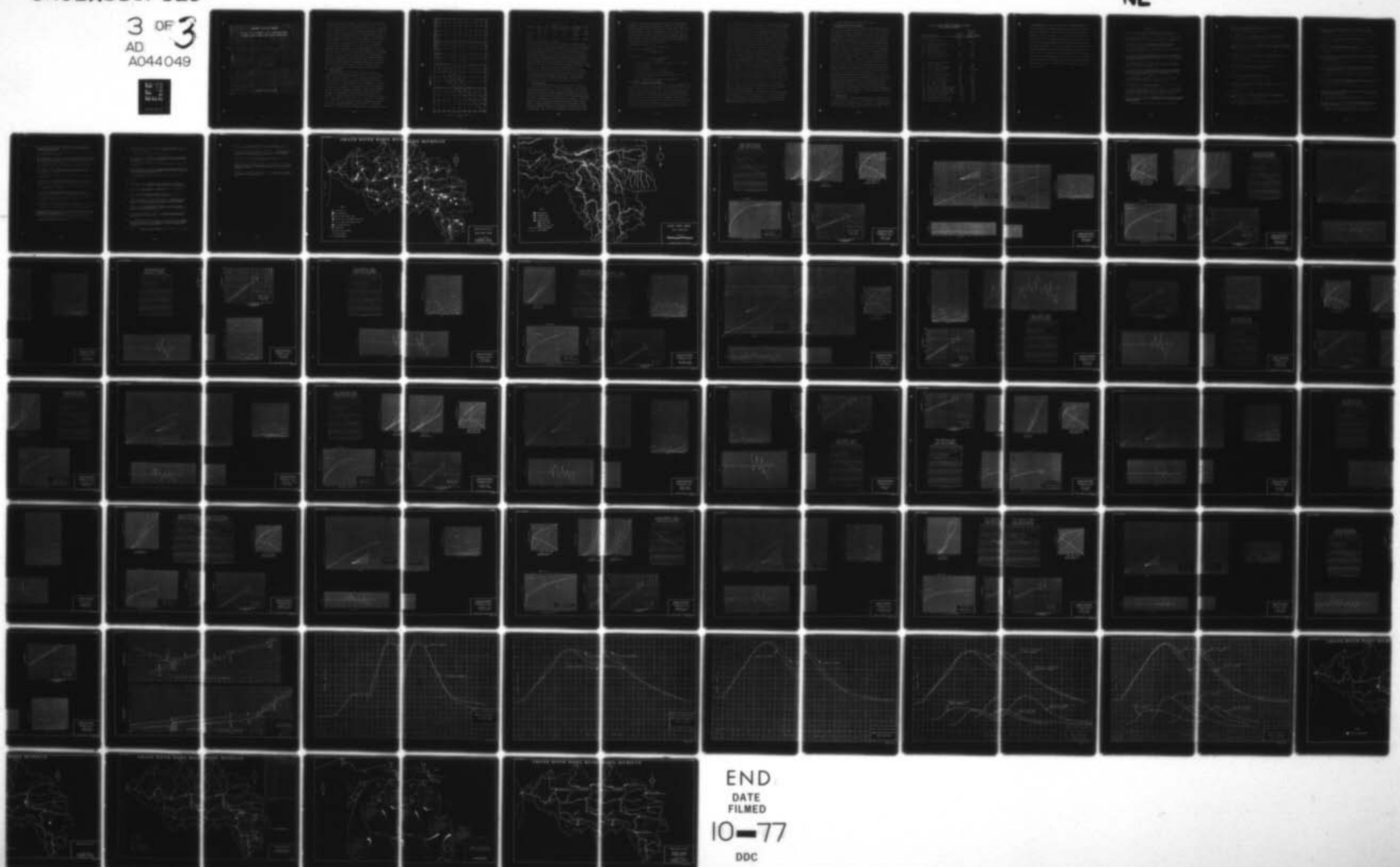

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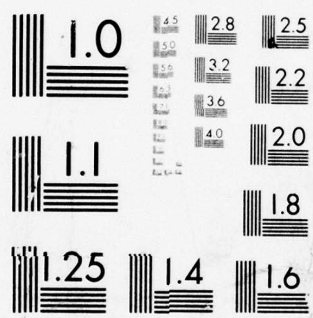
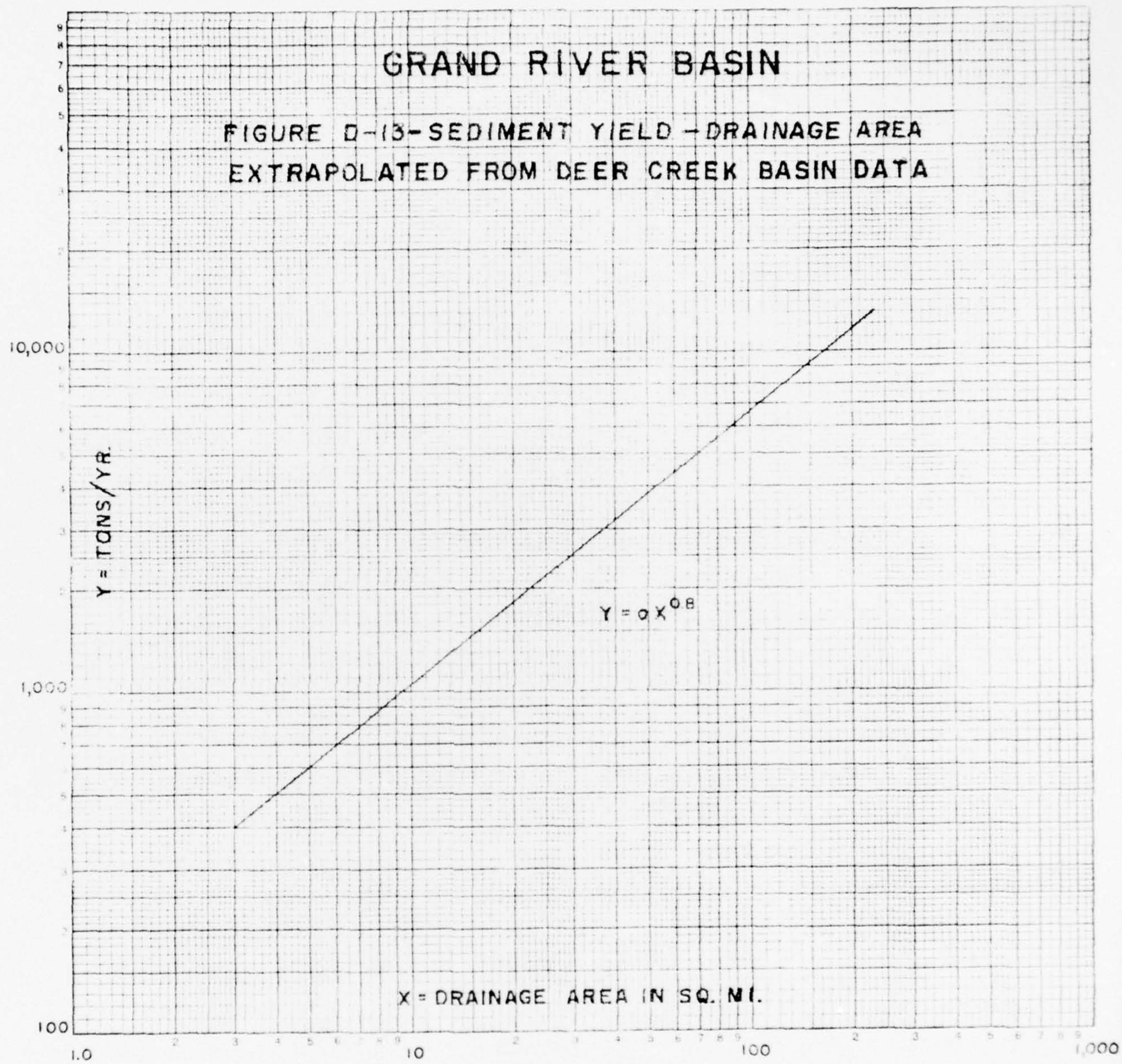


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

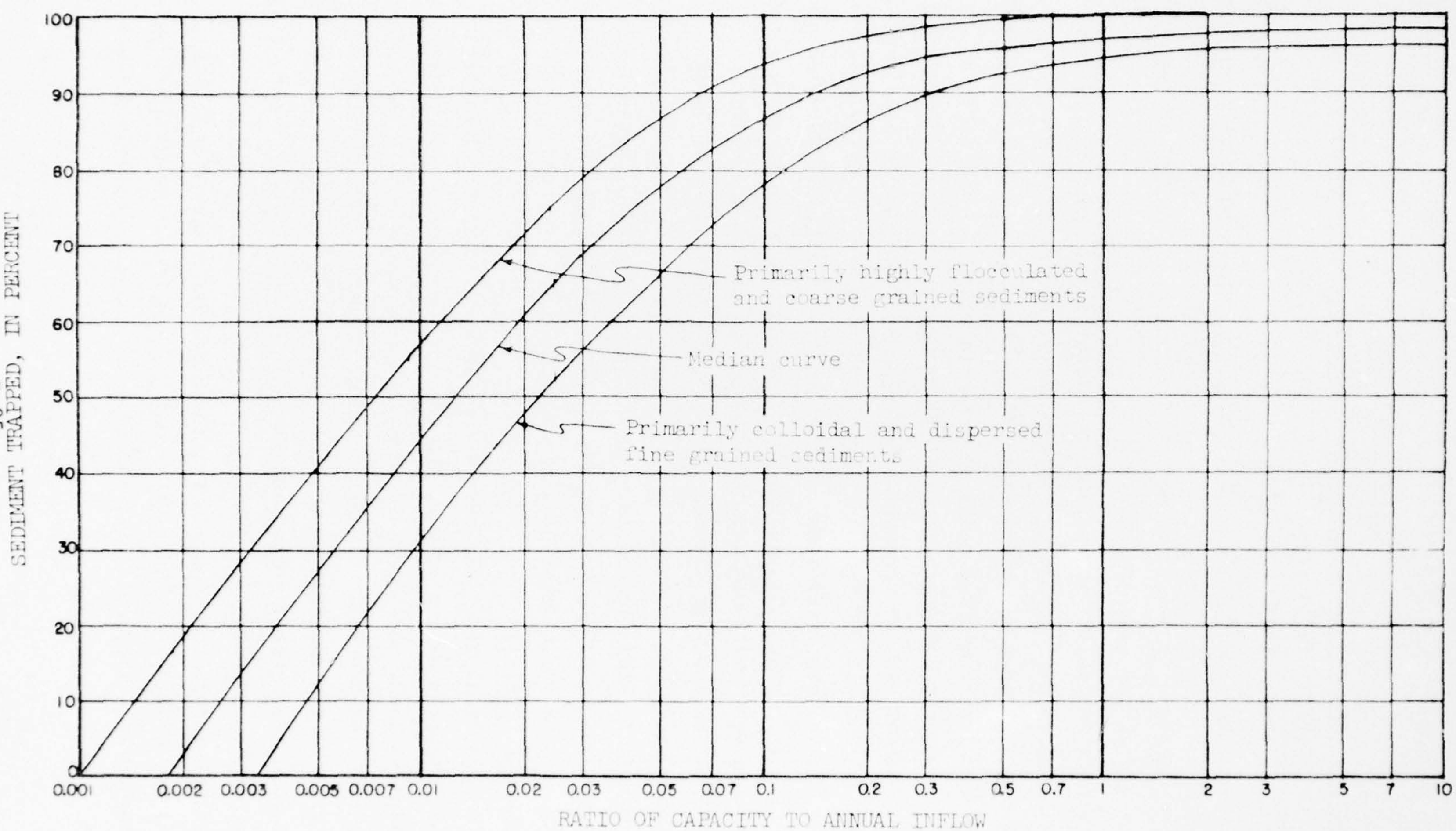

GRAND RIVER BASIN
FIGURE D-13-SEDIMENT YIELD-DRAINAGE AREA
EXTRAPOLATED FROM DEER CREEK BASIN DATA
10,000
1,000
100
Y = TONS/YR.
Y = aX^0.8
X = DRAINAGE AREA IN SQ. MI.
1.0
10
100
1,000

An analysis of hydrologic data for the Deer Creek Basin indicates an average discharge of 3.6 cubic feet per second = .22 cfsm. This value used in the relationship Y = 0.05X yields a Y value of 0.18 tons/hour, or 1,570 tons per year. This is the computed mean sediment yield from the 16.3 square mile drainage area in the Deer Creek Basin. Existing studies indicate that sediment yields vary roughly to the 0.8 power of the watershed drainage area. This approximation, if used to extrapolate the data from the 16.3 square mile Deer Creek Basin, yields the relationship shown graphically in Figure D-13. The sediment delivery ratio is the percent of the total gross erosion within a watershed that is delivered to a given downstream point. It follows that the sediment delivery ratios, assuming reasonably uniform geologic conditions, also are related by the 0.8 power of the drainage area. Estimates of sediment yield may be made using the sediment delivery ratio and computations of gross erosion provided that check points of sediment yield are available. Some measured quantitative data must be available that reliably reflect the level of sediment yield for the area in question and to which the computations may be tied.

36. TRAP EFFICIENCY

Sediment yield is a total quantity figure of the amount of sediment that is deposited at or passes a given point in a drainage system. Estimates of capacity loss from sediment accumulation in planned water impoundments are needed to determine design criteria. The efficiency of the trapping effect of an impoundment is a function of type and size. Figure D-14 (44) shows curves that may be used to estimate the trap efficiency of a reservoir. These curves relate the percent of the total sediment yield at the reservoir site that will be trapped in the reservoir to the capacity-inflow ratio of the reservoir. The capacity-inflow ratio is the ratio between the capacity of the reservoir in acre feet and the total inflow into the reservoir in acre feet. Reconnaissance reservoir sedimentation surveys were made on three small reservoirs within the Basin. Table D-21 summarizes the data obtained from these surveys. Consider the Elsie Pond

Figure D-14 -- Trap Efficiency of Reservoirs



Adopted from Brune, G.M. - Trans. AGU, V.34 - 3

TABLE D-21

Reservoir	Age (yrs)	D.A. (mi^2)	Orig Cap. (ac. ft.)	Acc. Sed. (ac. ft.)	Inflow (ac. ft/yr)	C/I
Elsie	100*	192	111	59	71,500	0.0016
Rockford	100*	225	89	45	84,000	0.0011
Carson City	100*	123	99	29	46,000	0.0022

*Actual age is not known - estimated

in reference to its C/I ratio and trap efficiency. Sediment yields shown in Figure D-13 should be representative for the type of physiography in the drainage area above the Elsie Pond. Figure D-13 shows that the average sediment yield for a 192 square mile drainage area would be about 12,000 tons per year. Table D-21 shows that the Elsie Pond has 59 acre feet of sediment accumulation. The sediment in the pond probably weighs about 1,300 tons per acre foot; total weight of 59 acre feet is 76,700 tons. The trap efficiency is 76,700/1,200,000 x 100 or about 6%. This value lies in the vicinity, on Figure D-14, where a reservoir with a very small C/I ratio (about 0.002) should be. This illustrates the low trap efficiency of small reservoirs with large drainage areas. Most reservoirs constructed under the P.L. 566 Small Watershed Protection Program have much higher C/I ratios, perhaps in the range 0.03 to 0.07. Studies and experience indicate the trap efficiencies of these reservoirs range from 70 to 95 percent.

37. CHANNEL STABILITY

The condition of stream beds with reference to their stability has been observed extensively in the Grand River Basin. Sand bottom channels and sandy bed load materials are very common within the Basin. Unstable stream channels, either aggrading or degrading, are not characteristic of the channels as they exist today. Stream beds have become adjusted to the present grade and hydrology of the system. A potential problem should be recognized, however, when structural works are considered. Changed hydrology and hydraulic gradients commonly induce channel bed changes. Channels will degrade and undermine road bridges or other works. They will fill and adversely affect drainage outlets,

or they will often move large volumes of materials into undesirable locations. Considerable research work has been done in the area of stream bed stability both in laboratory and field studies. Three major bed load transport formulas have emerged by which the intensity of a stability problem, existing or potential, may be assessed. The Meyer-Peter formula is adapted to gravel and coarse sand bed load materials. The Schoklitsch formula is adapted to medium sand to fine gravel, and the Haywood formula for fine to medium sand.

The Meyer-Peter formula is:

$$GS = (Aq^{2/3} S - Bd_m)^{3/2}$$

The Schoklitsch formula is:

$$GS = A \frac{S^{3/2}}{d^{1/2}} (q-qc)$$

and the Haywood is:

$$GS = \frac{(q^{2/3} S - Ad^{4/3})^{3/2}}{Bd^{1/3}}$$

GS = bed load transport in pounds per second per foot of average channel width.

A and B are constants

S = hydraulic gradient in feet per foot

q = discharge in cfs per foot of channel width

qc = critical discharge, discharge in cfs at which bed load starts to move

d or d_m = representative diameters of bed materials

38. SEDIMENT CONCENTRATION AND DAMAGES

Rates of sediment production within the Grand River Basin are not of the intensity of those of many other areas in the United States. The relief of the landscape under present hydrologic conditions is in near stable adjustment. This inhibits rapid and voluminous sedimentation rates and quantities. The lower magnitude of the quantities, however, does not alter the fact that the existing sediment sources and the resultant sediment yields constitute a problem. Problems from sediment are very often equated to damages to productive flood plain land, to channel filling and resulting drainage impairment, and to the rapid

loss of water storage capacity in reservoirs. Of these types of damages, reservoir sedimentation is the most pronounced. The data shown in Table D-21 indicate this, although the capacity loss figures are below those of other areas of the United States. Sedimentation damages in the Grand River Basin are primarily those that affect water quality and have characteristics more like those of a pollutant. The measured data on sediment concentration that is available for the Deer Creek Basin, as discussed in the section on sediment yield, is the only quantitative data found for use in analysis of sedimentation rates. U.S. Department of Agriculture miscellaneous publication No. 964 (45) and the Geological Survey Water-Supply Paper 1547 (46) have no listings either of reservoir sedimentation surveys or suspended load measurements for the Grand River Basin. Measurements are needed in the Basin to serve both as check points to tie in sediment routing analyses, and also for current measurements of sediment concentration in various segments of the drainage system. Much of the sediment in the drainage system is carried as suspended sediment. Bed load movement is significant in some channels. Opaque, murky water is very much in evidence in practically all channels during prolonged runoff periods both from rainfall and rapid snowmelt. Colloidal and the finer grained sediment particles persist as suspended sediment in the "quiet water" long after peak runoff has subsided. The damaging aspects of this suspended sediment are its effects on fish and wildlife and the unsuitability of the water for recreational purposes. Where the water is used for industrial purposes or for steam power generation filtering is necessary. The predominate source of sediment in the Grand River Basin appears to be sheet erosion from farm lands and from urban development. Acceleration of the long-term program of land treatment on farm land as well as the stabilization and treatment of sediment sources in urban areas, and in some cases roadways, appears to be the most feasible means of controlling and reducing the suspended sediment loads in the Grand River Basin.

SECTION VIII-FLUVIAL SEDIMENT PROJECT ANALYSIS

39. EXPECTED ACCUMULATION OF SEDIMENT

The expected accumulation of sediment in the proposed reservoir sites must be computed on an individual basis due to the many factors which must be taken into consideration. The local conditions should be investigated to determine whether more than the normal amount of sedimentation is to be expected. The effective sediment producing drainage area should be studied to determine that no areas of excessive erosion exist. The effective sediment producing drainage area can only be determined when it is known how many control structures are likely to be built on the stream. Water quality in the stream should be investigated to determine the amount of suspended sediment carried, temperature, and a chemical analysis of the stream water. The above factors largely determine the amount of sedimentation that will occur in a reservoir. The shape of the reservoir is also an important factor in the amount of organic sediment deposited. Water areas in reservoirs of over 10 feet in depth will not be subject to significant deposits of organic sediments, because water depth over ten feet greatly reduces the amount of sunlight that is available for plant growth. The storage loss in the proposed reservoirs over a period of approximately 100 years could be as small as 15 percent and as large as 45 percent, but must be determined on an individual basis. The amount of detrital sedimentation is not great when the rate of erosion has been stabilized. The erosion that does take place in a drainage basin is not significant compared to the capacity of the proposed reservoirs, and therefore it is doubtful that any precautions are necessary to minimize the amount of detrital sediment accumulating in the reservoirs from this cause.

40. STORAGE LOSSES

Storage losses in the existing reservoirs due to sediment accumulations have been due mainly to fluvial sedimentation having an amount of organic sediment ranging from 15 to 30 percent. The shallow reservoirs studied had a great deal of vegetation growing in them. The

TABLE D-22

ESTIMATED SEDIMENT TRAPPED IN PROPOSED RESERVOIRS OVER A PERIOD OF 50 YEARS

Reservoir Location		Drainage Area sq. mi.	Estimated Sediment Trapped over 50-year Period acre feet
JACKSON COMPLEX (3)			
7	Onondaga, Grand River	637	6,510
62S	Sandstone, Sandstone Creek	20	89
62M	Minard, Sandstone Creek	87	761
RED CEDAR COMPLEX (3)			
57C	Okemos, Red Cedar River	295	320
58	Williamston, Red Cedar River	235	1,340
59	Doan Creek, Doan Creek	42	420
16	Ravenna No. 2, North Branch Crockery Creek	45.5	444
19A	Rockford River, Rogue River	197	1,500
22	Labarge, Thornapple River	798	"Dry pool"
25	Duck Creek, Duck Creek	26	287
42	Prairie Creek, Prairie Creek	100	880
47A	Fish Creek, Fish Creek	150	1,220
51	Portland, Lookingglass River	312	2,200
74	Sand Creek, Sand Creek	41	402
109	Bear Creek, Bear Creek	29.3	287
110	Sleepy Hollow, Little Maple River	11.1	138
144	Columbia Creek, Columbia Creek	14.8	176
148	Lookingglass, Lookingglass River	15.2	180
149	Grub Creek, Grub Creek	9.8	130
180	No Name Creek, No Name Creek	9.1	122
171	Portage River, Portage River	30	309

existing vegetation is not only the cause of the organic sediment, but it also has greatly reduced the storage capacity and the recreational area of the reservoirs. In most of the existing reservoirs, the heavy vegetation severely hinders travel on the surface of the reservoirs. Careful analysis of the proposed reservoir sites will provide for the design and necessary maintenance of the reservoirs that will minimize the growth of vegetation. In the shallow areas of the proposed reservoirs, it may be necessary to cut and remove the vegetation periodically to prevent it from contributing organic sediment and reducing the recreational areas of the proposed reservoirs. The amount of fluvial sediment should also be studied by setting up stations to measure suspended sediment concentrations for an extended period on the major streams on the Grand River Basin.

SECTION IX
BIBLIOGRAPHY

1. U.S. Army, Corps of Engineers, Grand River Basin Data Book, B-1 to B-39, U.S. Army Engineer District, Detroit, (No Date)

   Data book describes the physical characteristics of the Grand River and its major tributaries. An inventory of the number and size of lakes within the Grand River basin is also presented.

2. U.S. Geological Survey, Water Resources Data for Michigan, U.S. Geological Survey, Lansing, Michigan, (1931 to present)

   Annual publication of surface water data that includes average daily flows, mean monthly runoff, instantaneous peak and low flows for year and the period of record.

3. U.S. Geological Survey, Compilation of Records of Surface Waters of the United States Through September 1950, Geological Survey Water Supply Paper 1307, 397 pp., U.S. Government Printing Office, Washington, D.C., (1958)

   A compilation of streamflow records that include average monthly and annual runoffs, and extreme runoff amounts from the period of record through September 1950.

4. U.S. Geological Survey, Compilation of Records of Surface Waters of the United States, October 1950 to September 1960, Geological Survey Water Supply Paper 1727, 379 pp., U.S. Government Printing Office, Washington, D. C., (1964)

   A compilation of streamflow records that include average monthly and annual runoffs, and extreme runoff amounts for the 10-year period of October 1950 to September 1960.

5. U.S. Weather Bureau, Daily River Stages, U.S. Government Printing Office, Washington, D. C., (1901-Present)

   Data includes average daily river stages, and miscellaneous data such as gage location, elevation of gage zero, drainage area, flood stage, highest stages for year and period of record, and highest and lowest monthly readings with dates of occurrence.

6. U.S. Army, Corps of Engineers, Supplement Flood and Natural Emergency Operations Manuals, U.S. Army Engineer District, Detroit, 41 pp., (February 1962)

   Handbook describing pertinent stream gage station data.

7. Chow, Ven Te, Handbook of Applied Hydrology, Chapter 14, McGraw-Hill Book Company, New York, N.Y., (1964)

The entire chapter deals with all aspects of runoff.

8. U.S. Geological Survey - Appendix E - Geology and Ground Water, Grand River Basin - Comprehensive Water Resources Study, 82 pp., U.S. Army Engineer District, Detroit, (1967)

Provides detailed data and descriptions of the Grand River.

9. U.S. Army, Corps of Engineers, Routing of Floods through River Channels, Engineering Manual 1110-2-1400, 73 pp., U.S. Government Printing Office, Washington, D.C., (March 1960)

Technical manual that describes routing procedures.

10. U.S. Army, Corps of Engineers, Streamflow and Reservoir Routing, Grand River Basin Technical Paper No. 1, 50 pp., U.S. Army Engineer District, Detroit, (April 1967)

Methods and procedures of routing streamflows and reservoir routings are described in detail and illustrated.

11. Morris, Henry M., Applied Hydraulics in Engineering, p. 165-169, Ronald Press Company, New York, N.Y., (1963)

Descriptions and classifications of hydraulic structures are provided.

12. Davis, Calvin, Handbook of Applied Hydraulics, p. 5, McGraw-Hill Book Company, New York, N.Y., (1952)

Description of valley storage is provided.

13. U.S. Army, Corps of Engineers, Appendix C - Climate, 48 pp., Grand River Basin Comprehensive Water Resources Study, U.S. Army Engineer District, Detroit, (1967)

A detailed description of the Grand River basin's climate is provided.

14. U.S. Weather Bureau, Rainfall Intensity - Duration - Frequency Curves, Technical Paper No. 16, 53 pp., U.S. Government Printing Office, Washington, D. C., (December 1955)

This paper presents rainfall intensity-duration curves for durations of 5 minutes to 24 hours, and return periods of 2, 5, 10, 25, 50 and 100 years for selected stations throughout the U.S.

15. Schwartz, H.E., Determination of Flood Frequencies in a Major Drainage Basin, INGG, International Association of Scientific Hydrology, General Assembly of Toronto, VIII, (September 1957)

Methods are presented to determine flood frequency statistics.

16. Ezekiel, Mordecai, Methods of Correlation Analysis, John Wiley & Son, 531 pp., New York, (1941)

Methods are presented that determine frequency statistics.

17. Beard, L.R., Statistical Methods in Hydrology, U.S. Army, Corps of Engineers, 61 pp., Detroit District, (January 1962)

Methods are presented that determine and evaluate frequency statistics.

18. U.S. Geological Survey, Low Flow Characteristics of the Grand River and its Tributaries, Water Resources Division, 2 pp., Lansing, Michigan, (March 1965)

Describes results of low flow studies made by U.S. Geological Survey for the Grand River Basin.

19. U.S. Army, Corps of Engineers, Determining Storage Requirements in the Grand River Basin, Grand River Basin Technical Paper No. 6, U.S. Army Engineer District, Detroit, (May 1967)

Describes and illustrates in detail methods used to determine storage requirements to meet a variety of needs within the Grand River Basin.

20. Stall, John B., Reservoir Mass Analysis by a Low Flow Series, Journal of the Sanitary Engineering Division, pp. 21-40, ASCE, Vol. 88, No. SA5, Proc. Paper 3283, (September 1962)

Describes methods of evaluating storage requirements to meet water needs.

21. Snyder, Franklin F., Computation of Storage Allocations for Yields of Different Dependability, 6 pp., U.S. Army, Corps of Engineers, Washington, D.C., (9 May 1966)

Describes and illustrates method of evaluating storage requirements of a reservoir for different reliabilities.

22. U.S. Army, Corps of Engineers, Discharges for Ungaged Areas Within the Grand River Basin, Grand River Basin Technical Paper No. 2, 15 pp., U.S. Army Engineer District, Detroit, (April 1967)

Methods and procedures for determining flood and monthly flows for ungaged areas are described in detail and illustrated.

23. U.S. Army, Corps of Engineers, Regional Flood Frequency Study - Grand River Drainage Basin, 9 pp., U.S. Army Engineer District, Detroit, (February 1962)

Describes in detail statistical analysis of flood records within the Grand River Basin.

24. U.S. Army, Corps of Engineers, Estimating Evapotranspiration Losses Within the Grand River Basin, Grand River Basin Technical Report No. 3, 7 pp., U.S. Army Engineer District, Detroit, (May 1967)

Describes in detail the derivation of a method of evaluating evapotranspiration losses for use in Grand River Basin studies.

25. U.S. Weather Bureau, Evaporation Maps for the United States, Technical Paper No. 37, plate 3, U.S. Government Printing Office, Washington, D.C., (1959)

Map of U.S. indicating relationship between lake and pan evaporation rates.

26. Hargreaves, G.H., Irrigation Requirements Based on Climatic Data, Irrigation and Drainage, Proceedings American Society of Civil Engineers, Journal Division, pp. 1-10, Vol. 82, NOJR3, (November 1956)

Text describes a method of evaluating transpiration losses of plant life based on climatic data.

27. Criddle, W.D., Methods of Computing Consumptive Use of Water, Proceedings American Society of Civil Engineers, Journal Division, Irrigation and Drainage, pp. 1-27, Vol. 84, No. IR1, (January 1958)

List monthly daytime coefficients for various latitudes for application in determining transpiration losses.

28. U.S. Department of Agriculture, Soil, The Yearbook of Agriculture, pp. 717-718, U.S. Government Printing Office, Washington, D.C., (1957)

Text describes lateral growth of various tree root systems.

29. Michigan Water Resources Commission, Report No. 2, Deer-Sloan Basin, Precipitation Studies 1956-1959, Hydrologic Studies of Small Watersheds in Agricultural Areas of Southern Michigan, 6 pp., Michigan Water Resources Commission, Lansing, Michigan, (August 1960)

Report that presents data collected by an intensive precipitation gage network for a 25 square mile area.

30. American Society of Civil Engineers, Hydrology Handbook, Manuals of Engineering Practice No. 28, American Society of Civil Engineers, New York, N.Y., (1949)

Text describes the infiltration process.

31. U.S. Army, Corps of Engineers, Infiltration Rates Within the Grand River Basin, Grand River Technical Paper No. 5, 18 pp., U.S. Army Engineer District, Detroit, (May 1967)

Describes in detail infiltration studies made by the Corps of Engineers.

32. Battelle Memorial Institute, Structure of the Economy of the Grand River Basin Service Area and Sub-Areas, Battelle Memorial Institute, Columbus, Ohio, (2 April 1964)

Describes the land use of the various sub-areas within the Grand River Basin.

33. Not used.

34. Mackenthun, K. M., A Review of Algae, Lake Weeds and Nutrients, Journal Water Pollution Control Federation, Vol. 34, Jan-Dec. 1962

35. Brune, G.M., Trap Efficiency of Reservoirs, Trans. American Geophysical Union, V. 34-3

36. Brown, C.B., The Control of Reservoir Silting, U.S. Dept. of Agriculture, U.S. Government Printing Office 1943

37. State of Michigan, Water Resources Commission, Hydrologic Studies of Small Watersheds in Agricultural Areas of Southern Michigan, Report No. 1, Deer-Sloan Basin, June 1958

38. Musgrave, G.W., The Quantitative Evaluation of Factors in Water Erosion - A First Approximation. Journal of Soil and Water Conservation. Vol. 2, Number 3, July 1948.

39. U.S. Agricultural Research Service, A Universal Equation for Predicting Rainfall-Erosion Losses. ARS Special Report ARS 22-66, March 1961

40. U.S. Department of Agriculture, Soil Conservation Service, Procedure for Determining Rates of Land Damage, Land Depreciation and Volume of Sediment Produced by Gully Erosion, Technical Release No. 32, July 1966.

41. Lane, E. W., Design of Stable Channels. Trans. ASCE, Vol. 120, 1955.

42. Dunn, E. S., Tractive Resistance of Cohesive Channels. Journal of Soil Mechanics and Foundation Division, ASCE, June 1959.

43. State of Michigan, Water Resources Commission. Hydrologic Studies of Small Watersheds in Agricultural Areas of Southern Michigan, Report No. 1, Deer-Sloan Basin, June 1958.

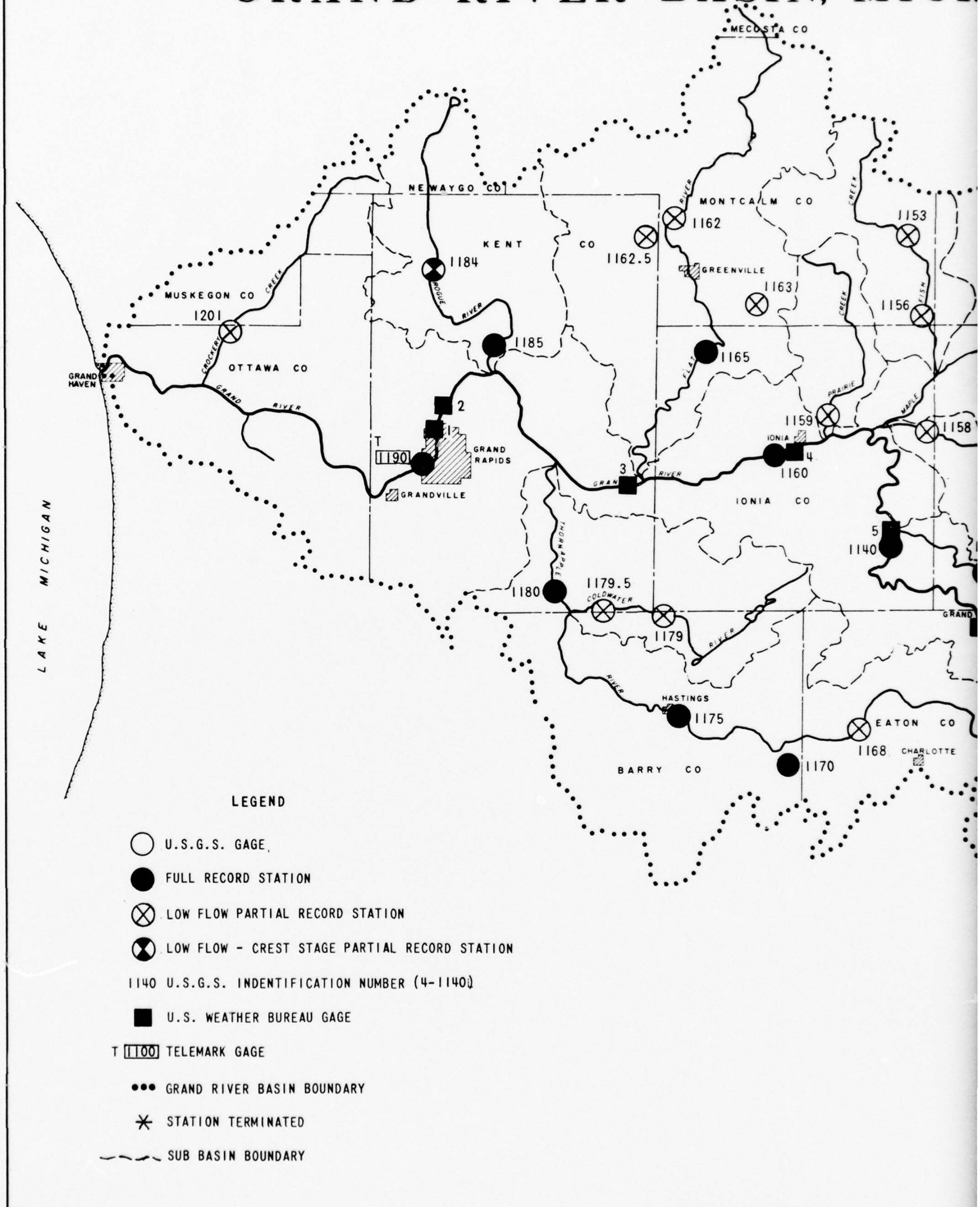
44. From Brune, Gunnar M. Trap Efficiency of Reservoirs, Trans. AGU, Vol. 34, No. 3, June 1953. p. 407-418.

45. Miscellaneous publication No. 964, U.S. Department of Agriculture, Summary of Reservoir Sediment Deposit in Surveys Made in the United States Through 1960. (Interagency Subcommittee on Sedimentation). May 1964.

46. Geological Survey Water-Supply Paper 1547 - Inventory of Published and Unpublished Sediment Load Data, U.S. and Puerto Rico, 1950-60; 1962.

CORPS OF ENGINEERS

GRAND RIVER BASIN, MICH



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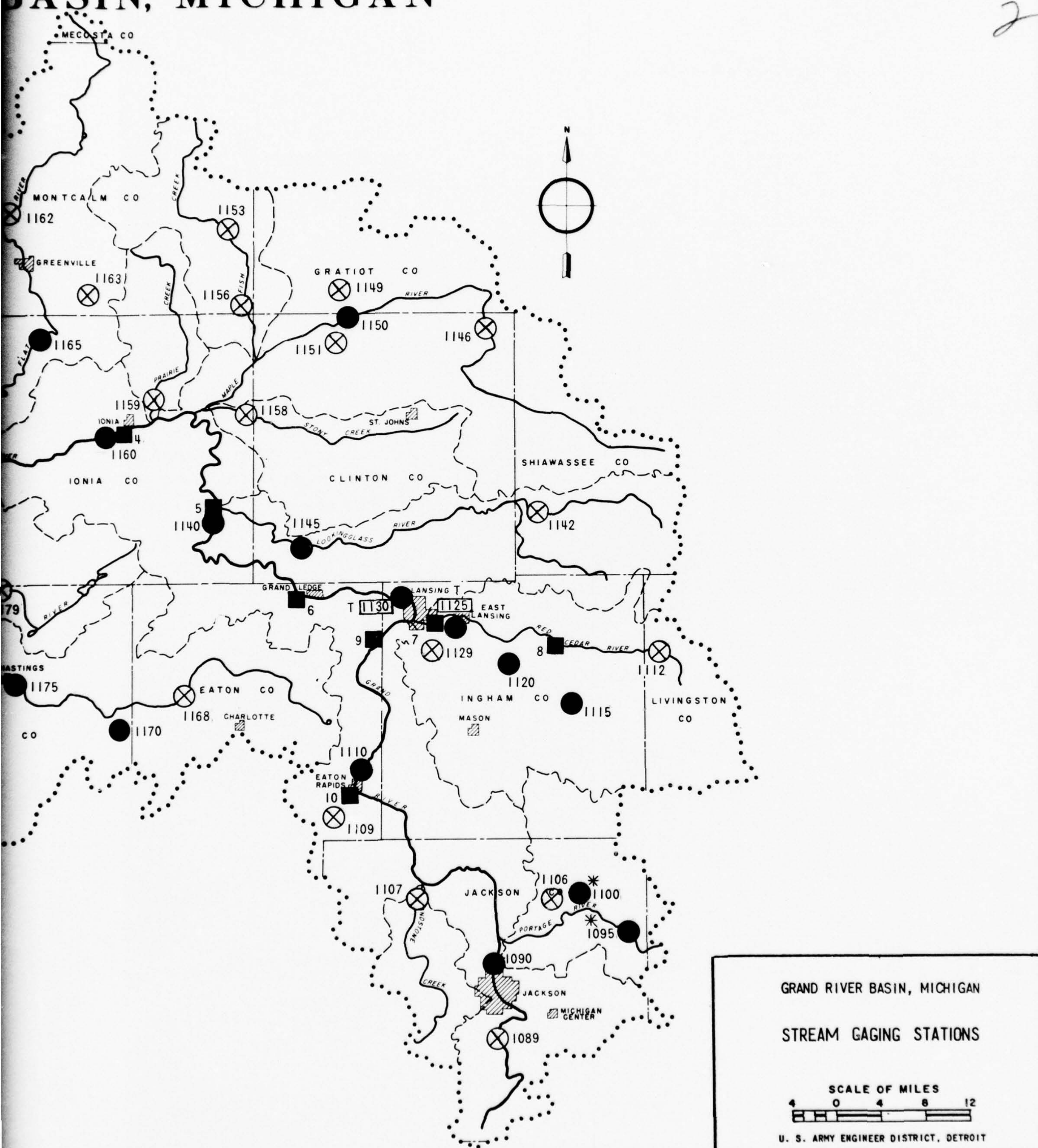

GRAND RIVER BASIN, MICHIGAN

STREAM GAGING STATIONS

SCALE OF MILES

4 0 4 8 12

U. S. ARMY ENGINEER DISTRICT, DETROIT

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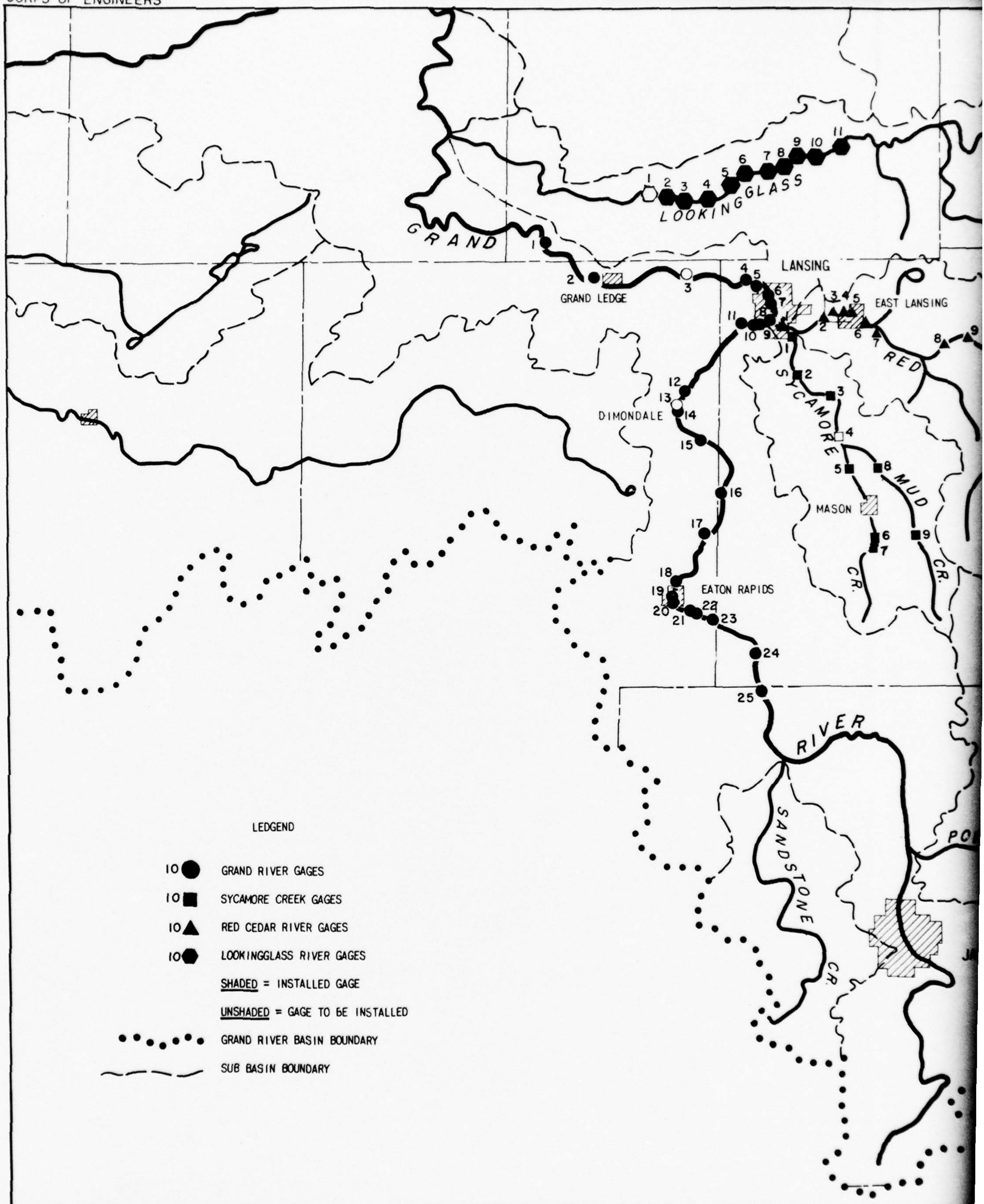

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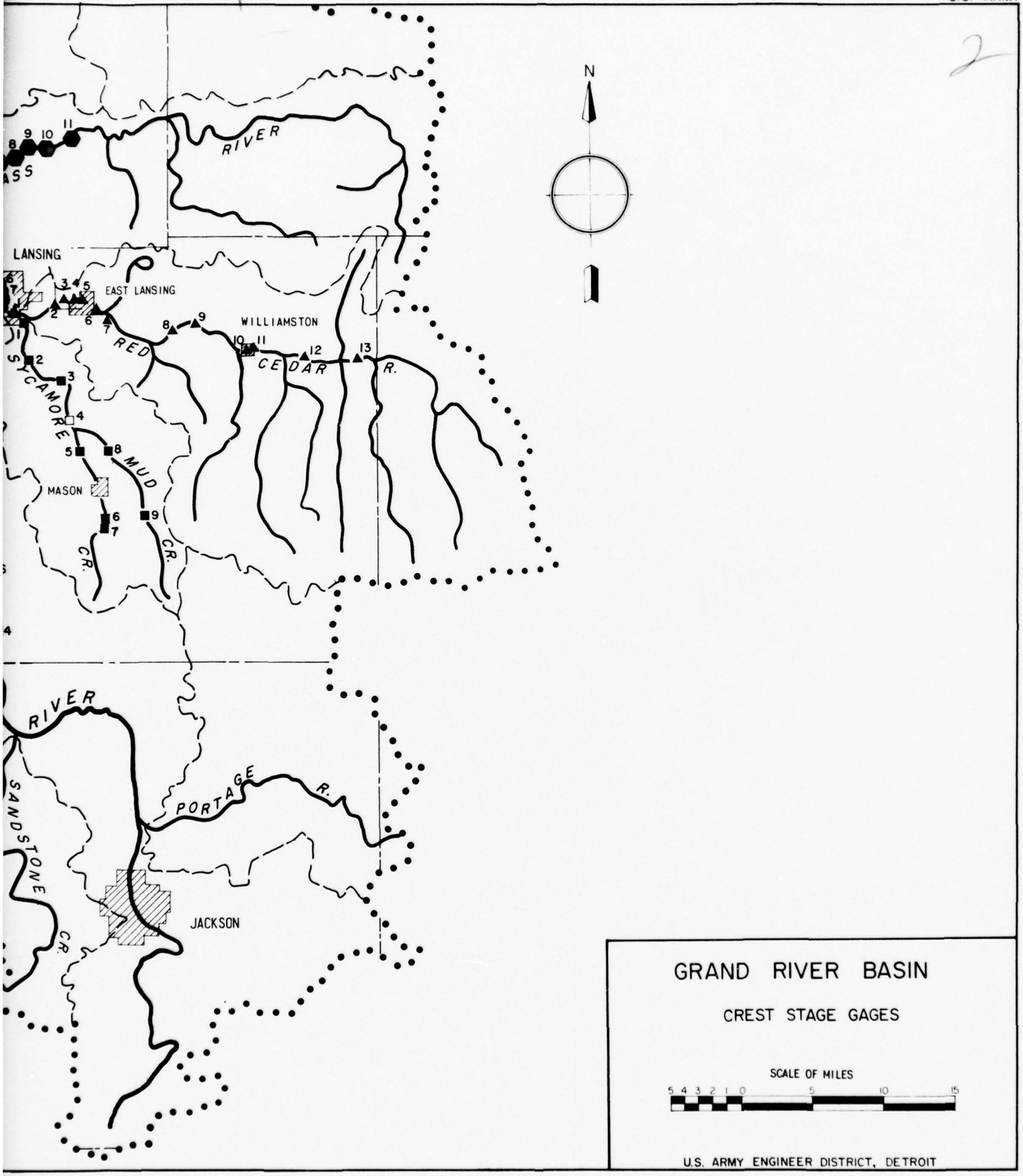
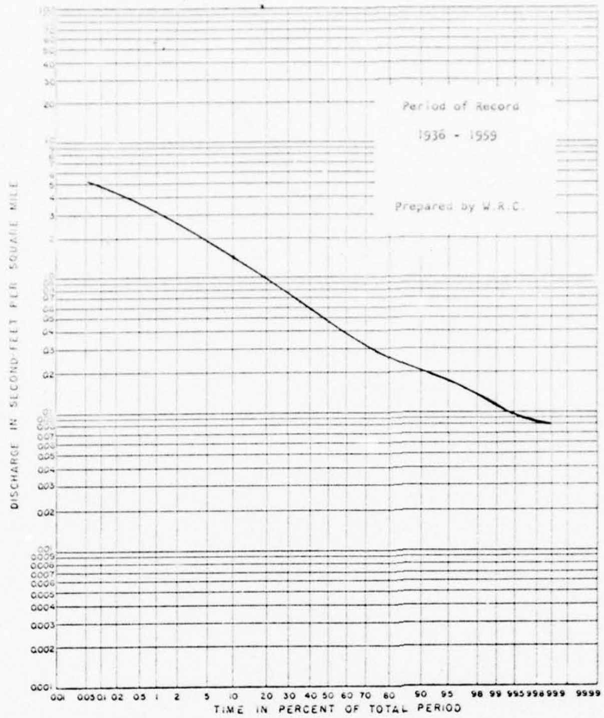
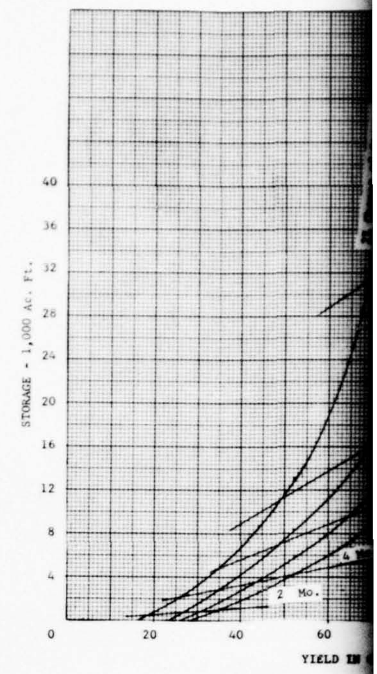


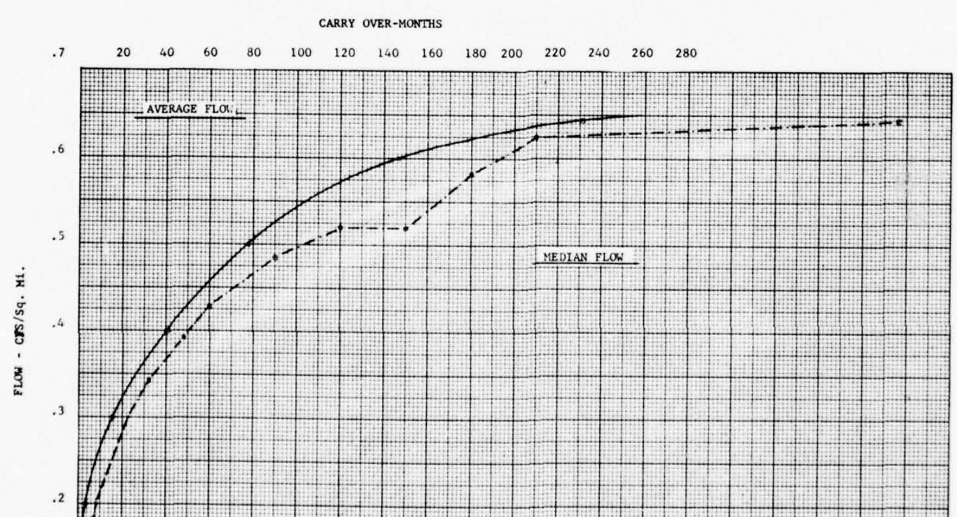
PLATE D-2

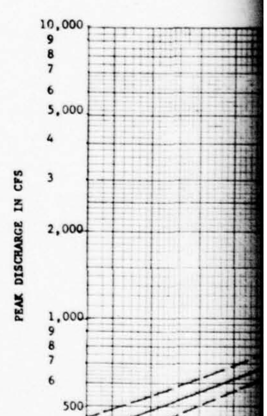
FLOW DURATION CURVE
GRAND RIVER AT JACKSON
Drainage Area 174 square miles

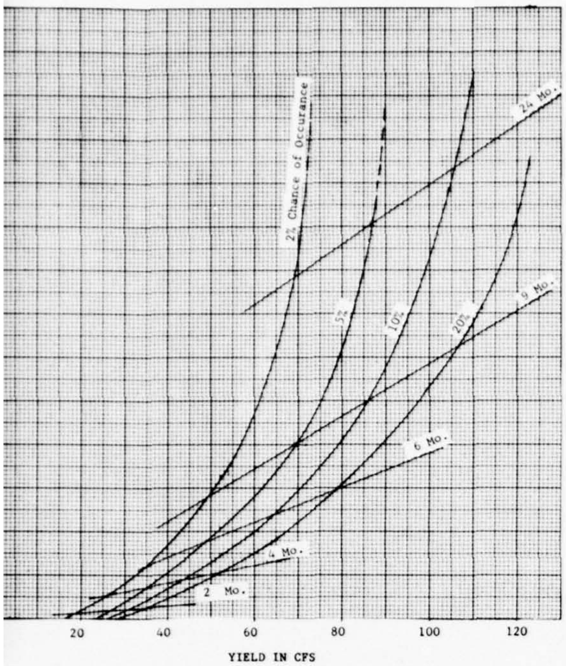




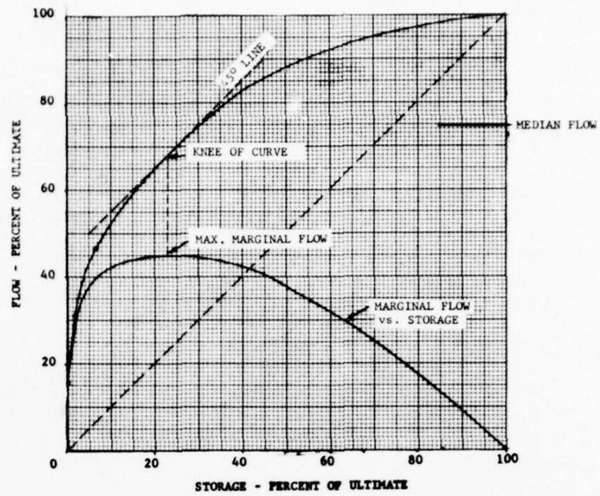
Storage - Yie
GRAND RIVER A



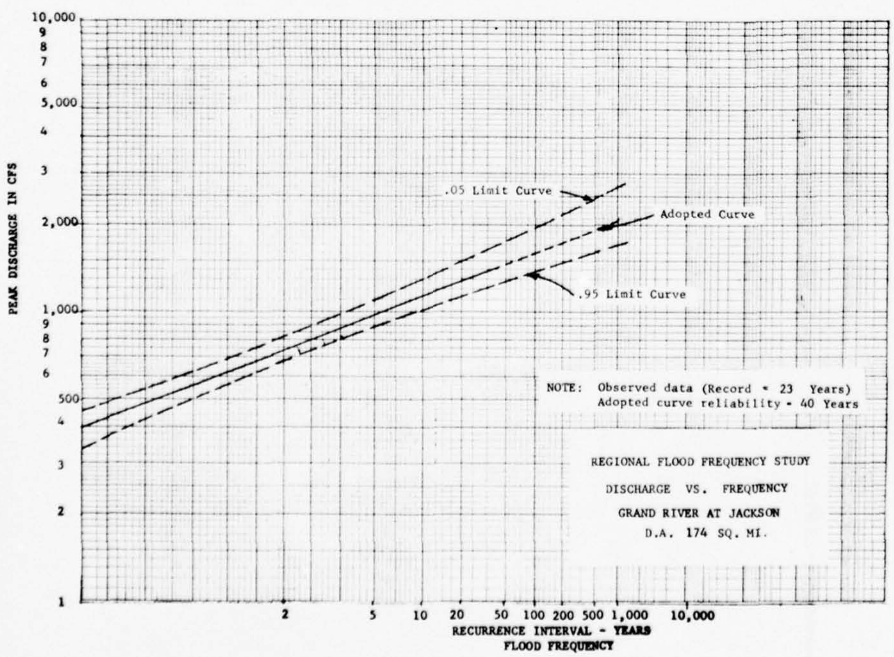




Storage - Yield Curve
GRAND RIVER AT JACKSON



Optimum Flow - Storage Development
GRAND RIVER AT JACKSON



REGIONAL FLOOD FREQUENCY STUDY

DISCHARGE VS. FREQUENCY

GRAND RIVER AT JACKSON

D.A. 174 SQ. MI.

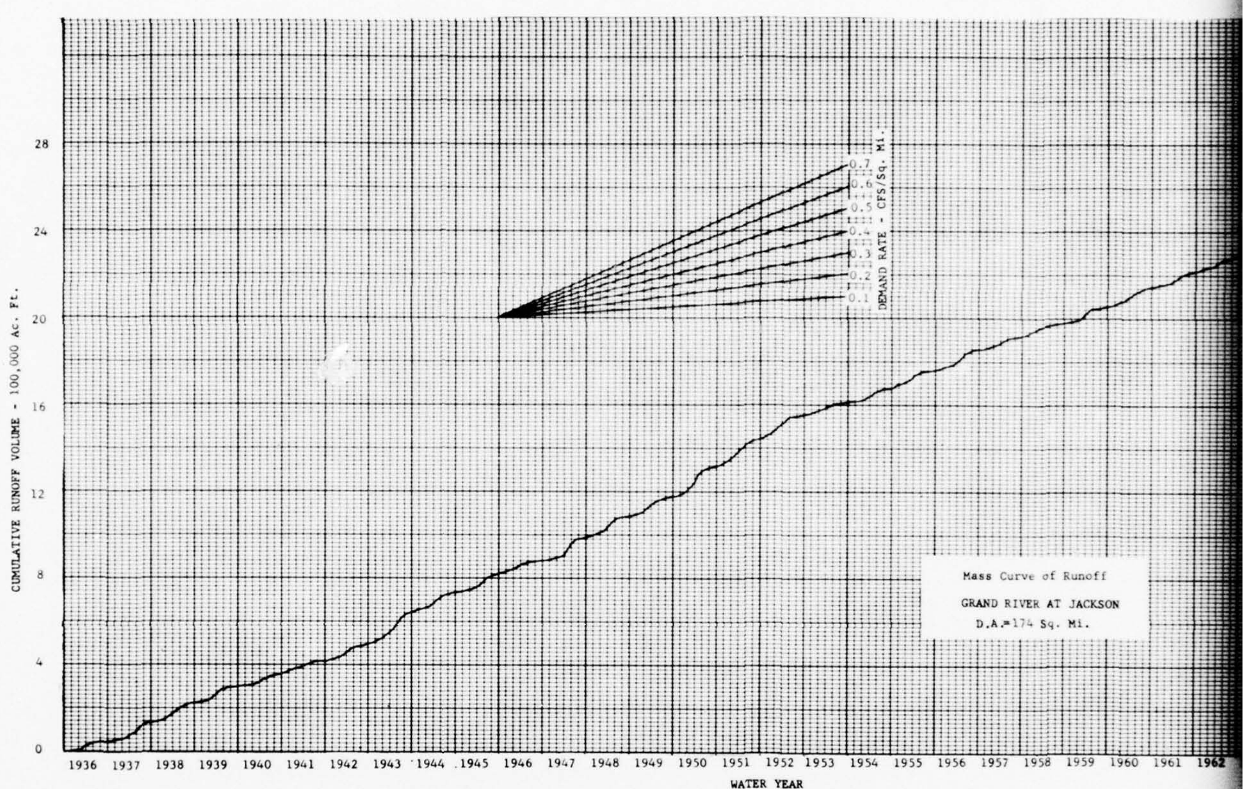
GRAND RIVER BASIN

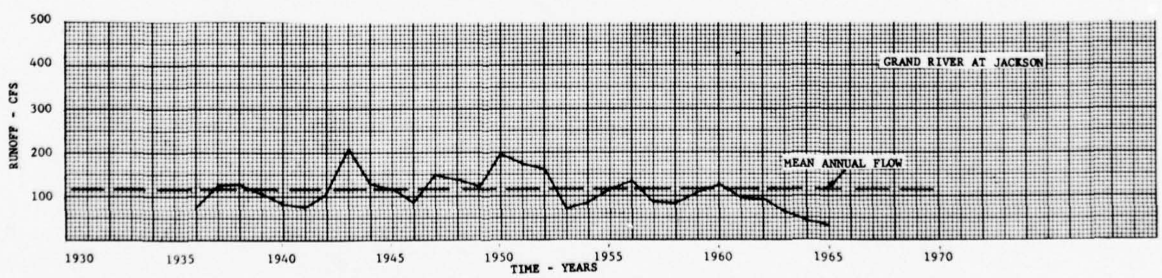
QUANTITATIVE STUDY OF STREAMFLOW DATA

GRAND RIVER AT JACKSON

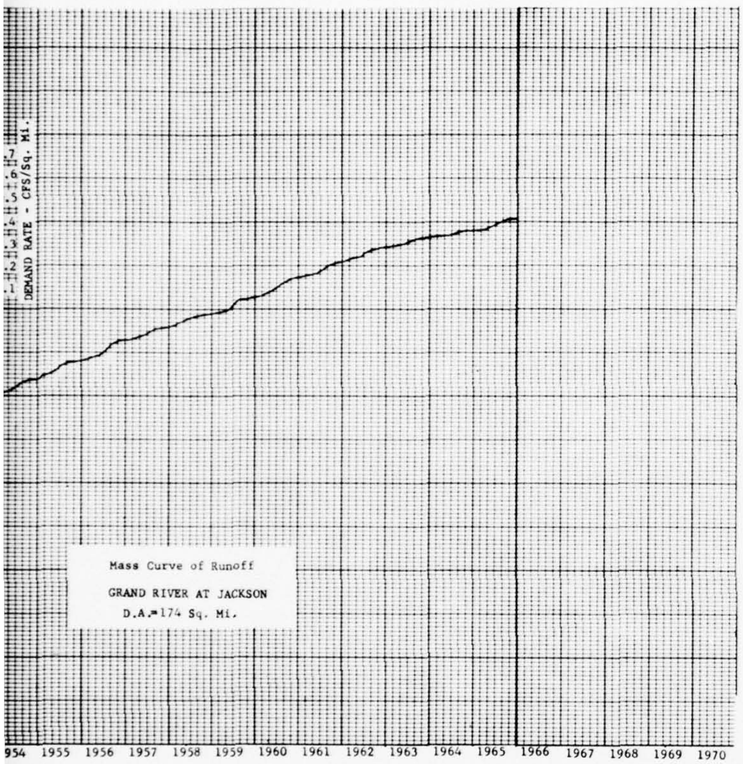
U.S. ARMY ENGINEER DISTRICT, DETROIT

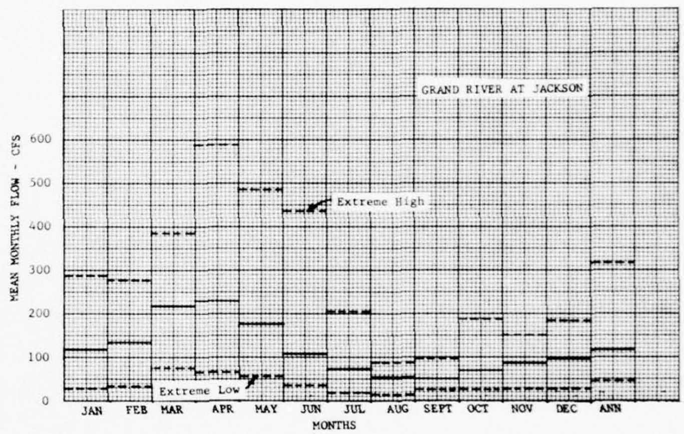
PLATE D-3A

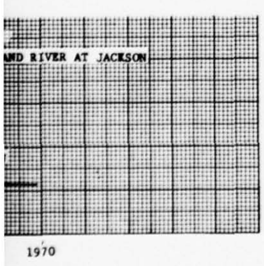

CUMULATIVE RUNOFF VOLUME - 100,000 Ac. Ft.
28
24
20
16
12
8
4
0
0.7
0.6
0.5
0.4
0.3
0.2
0.1
DEMAND RATE - CFS/Sq. Mi.
Mass Curve of Runoff
GRAND RIVER AT JACKSON
D.A.=174 Sq. Mi.
1936 1937 1938 1939 1940 1941 1942 1943 1944 1945 1946 1947 1948 1949 1950 1951 1952 1953 1954 1955 1956 1957 1958 1959 1960 1961 1962
WATER YEAR


RUNOFF - CFS
500
400
300
200
100
GRAND RIVER AT JACKSON
MEAN ANNUAL FLOW
1930 1935 1940 1945 1950 1955 1960 1965 1970
TIME - YEARS

2





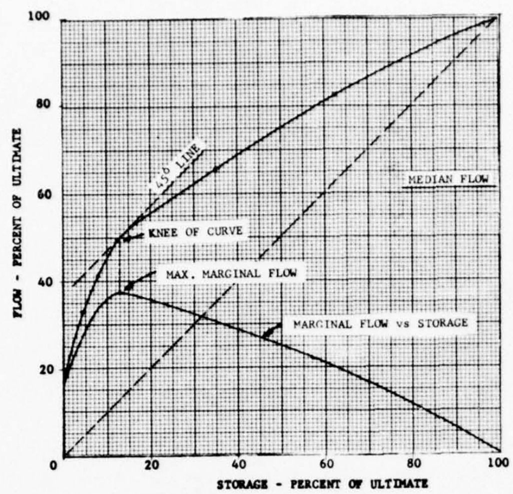


GRAND RIVER BASIN

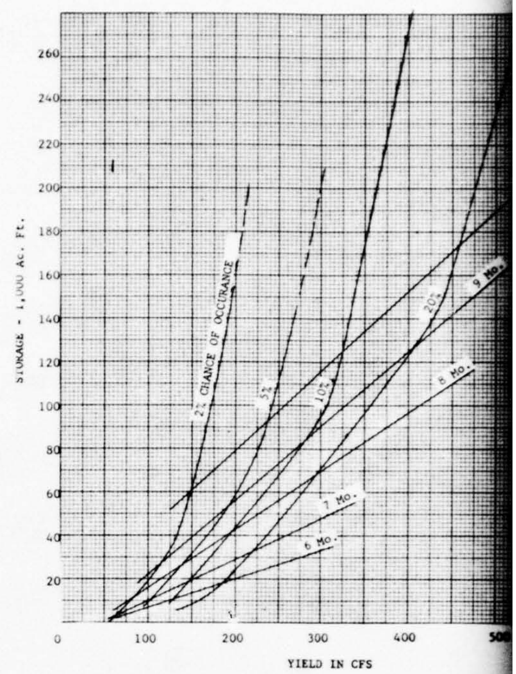
QUANTITATIVE STUDY OF STREAMFLOW DATA

GRAND RIVER AT JACKSON

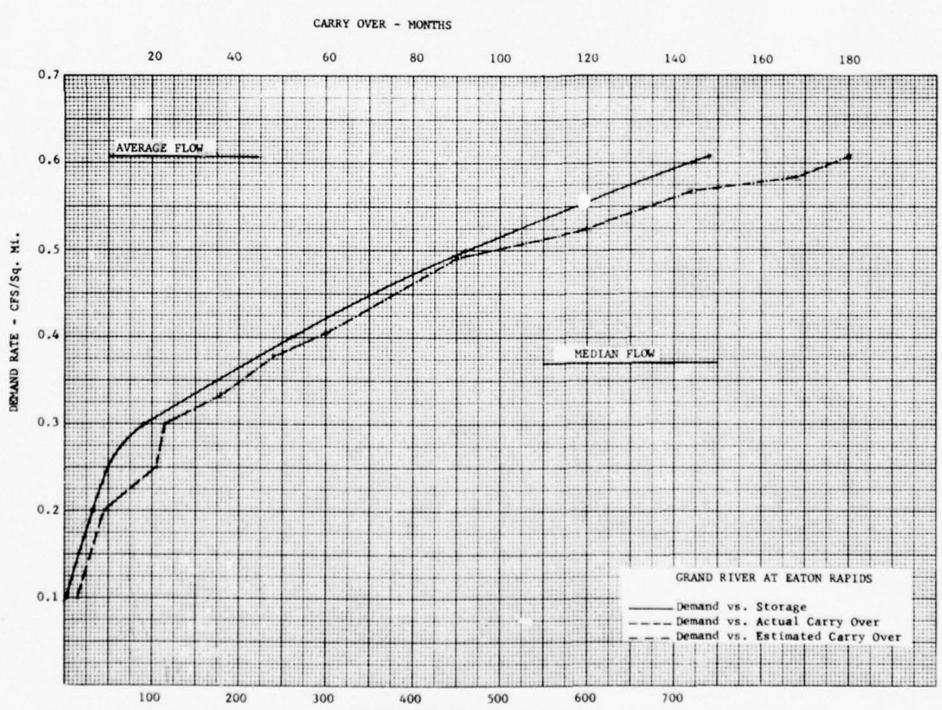
U.S. ARMY ENGINEER DISTRICT, DETROIT

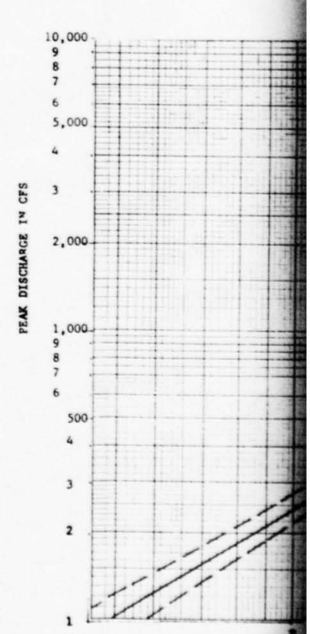


Optimum Flow - Storage Development
GRAND RIVER AT EATON RAPIDS



Storage - Yield Curve
GRAND RIVER AT EATON RAPIDS





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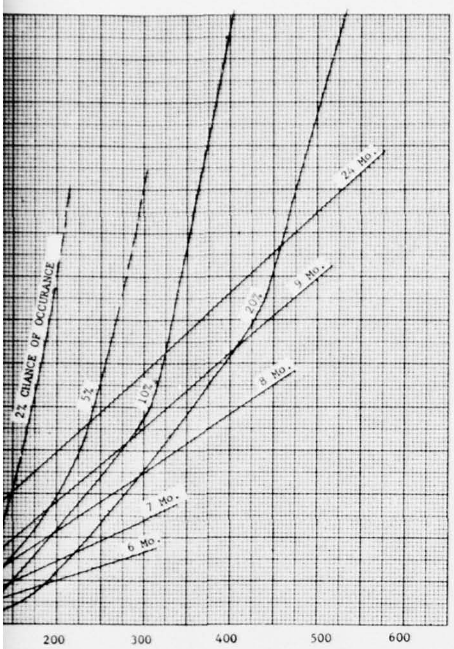
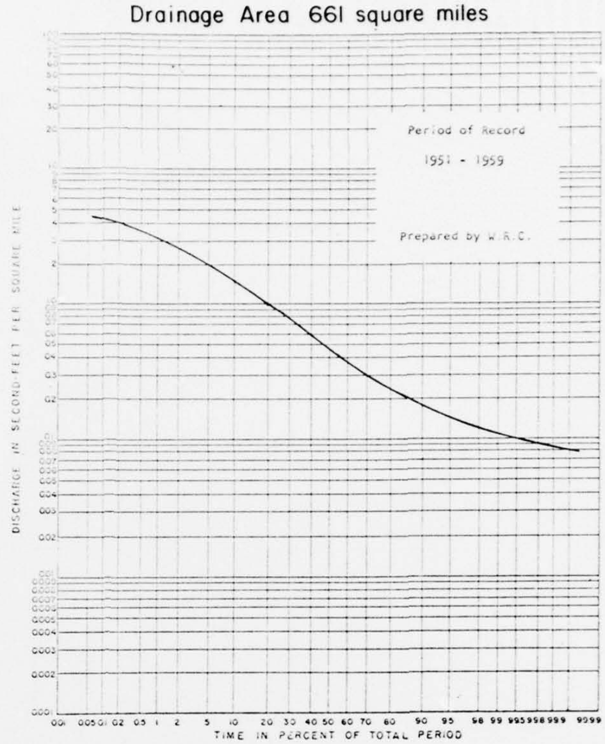
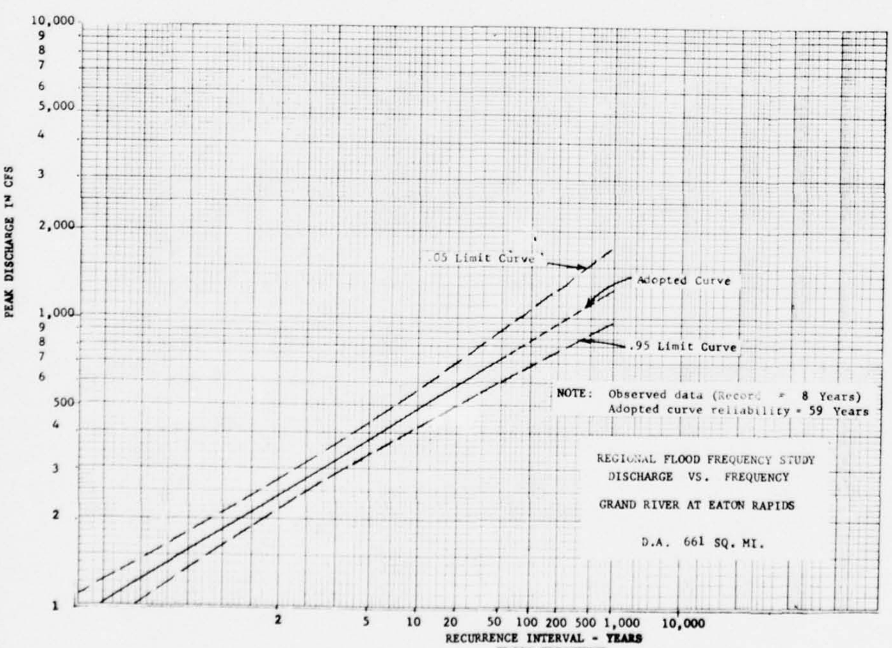


YIELD IN CFS

Storage - Yield Curve
GRAND RIVER AT EATON RAPIDS

FLOW DURATION CURVE
GRAND RIVER AT EATON RAPIDS
Drainage Area 661 square miles





RECURRENCE INTERVAL - YEARS
FLOOD FREQUENCY

GRAND RIVER BASIN
QUANTITATIVE STUDY OF STREAMFLOW DATA

GRAND RIVER AT EATON RAPIDS

U.S. ARMY ENGINEER DISTRICT, DETROIT

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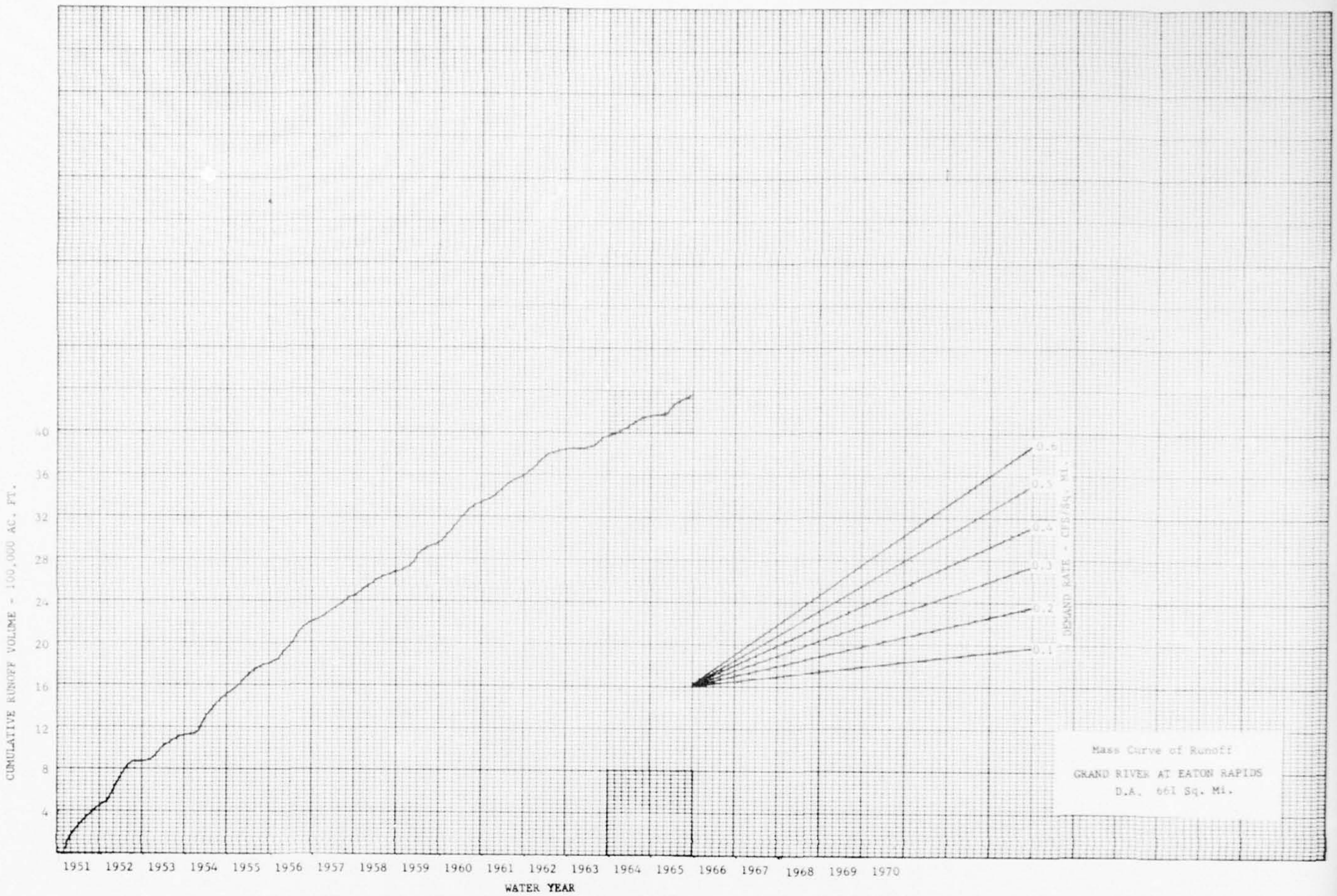

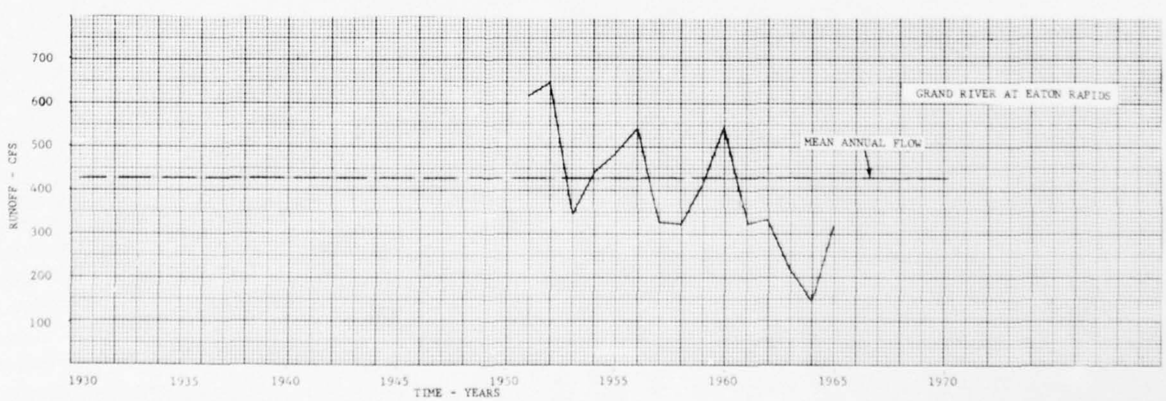

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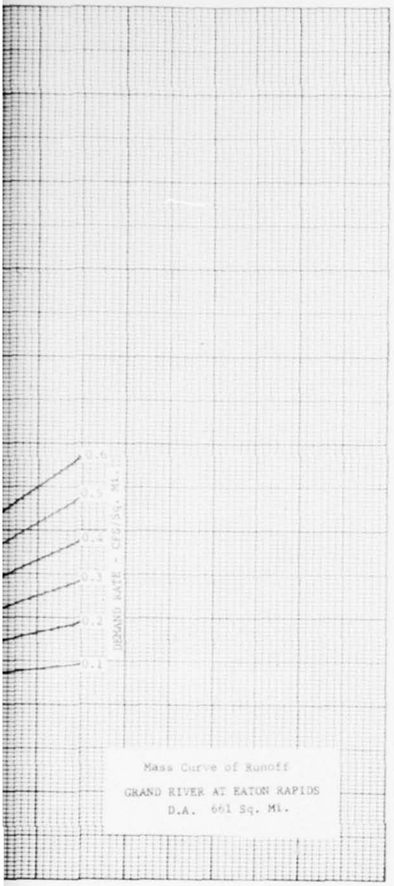
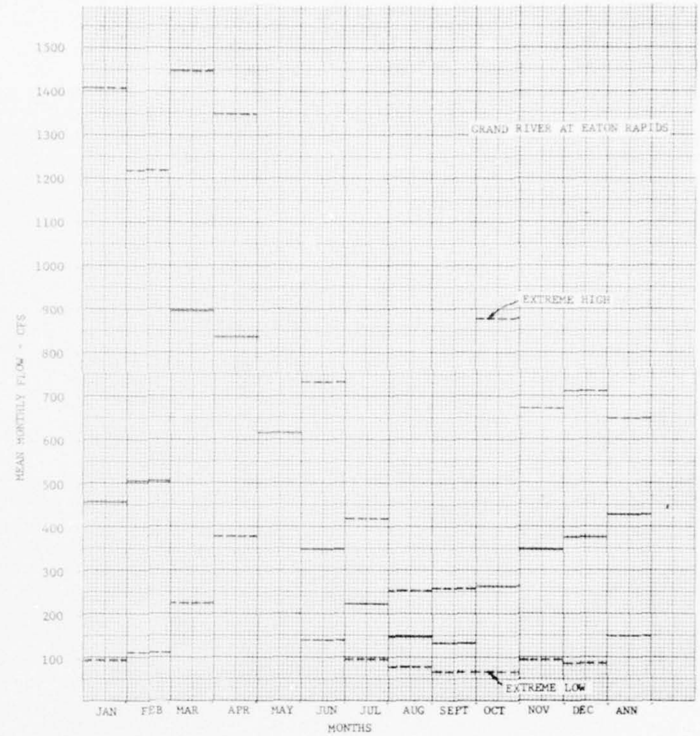
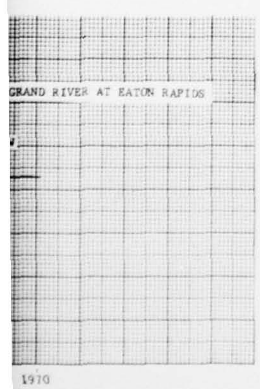






GRAND RIVER BASIN

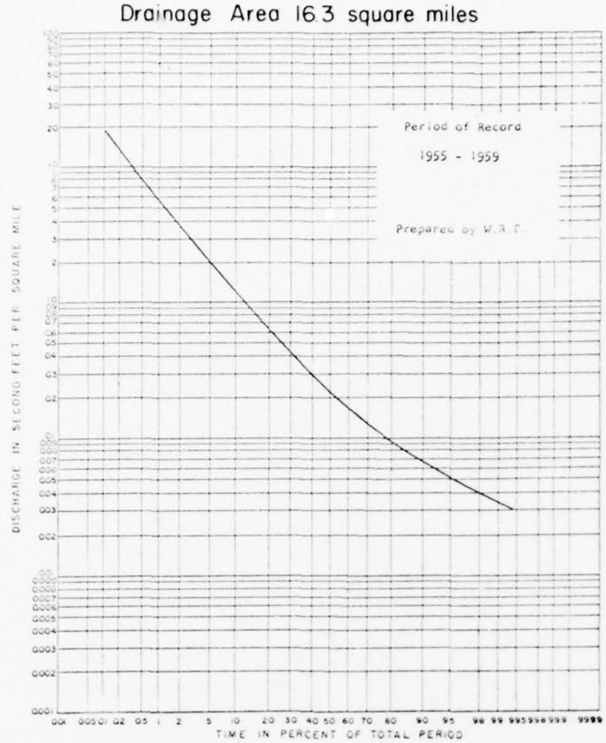
QUANTITATIVE STUDY OF STREAMFLOW DATA

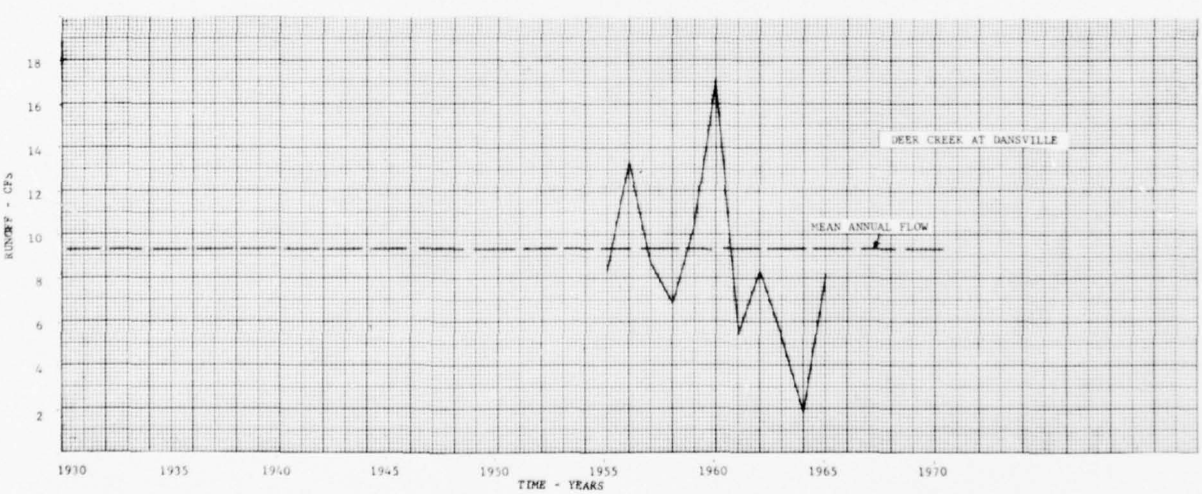
GRAND RIVER AT EATON RAPIDS

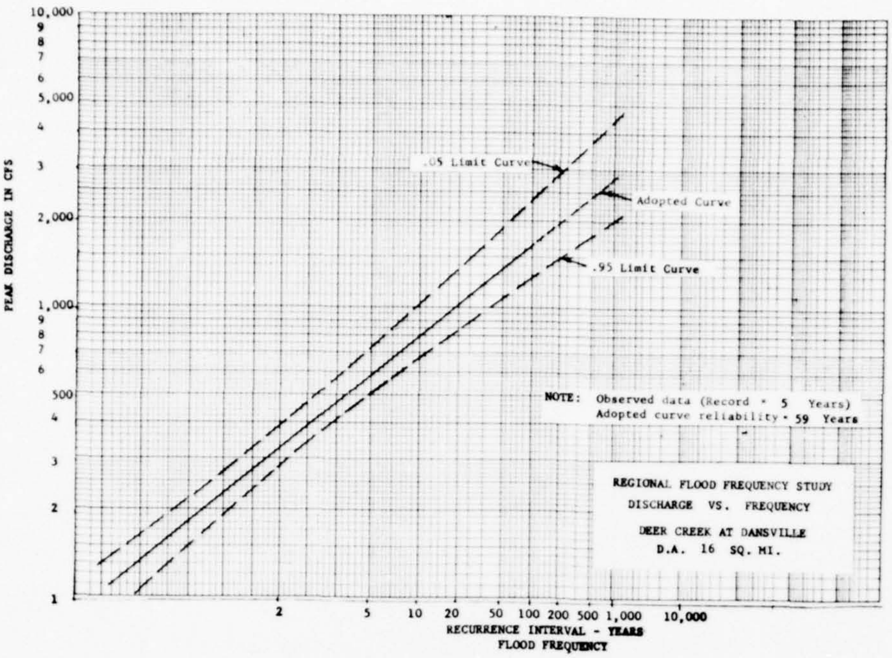
U.S. ARMY ENGINEER DISTRICT, DETROIT

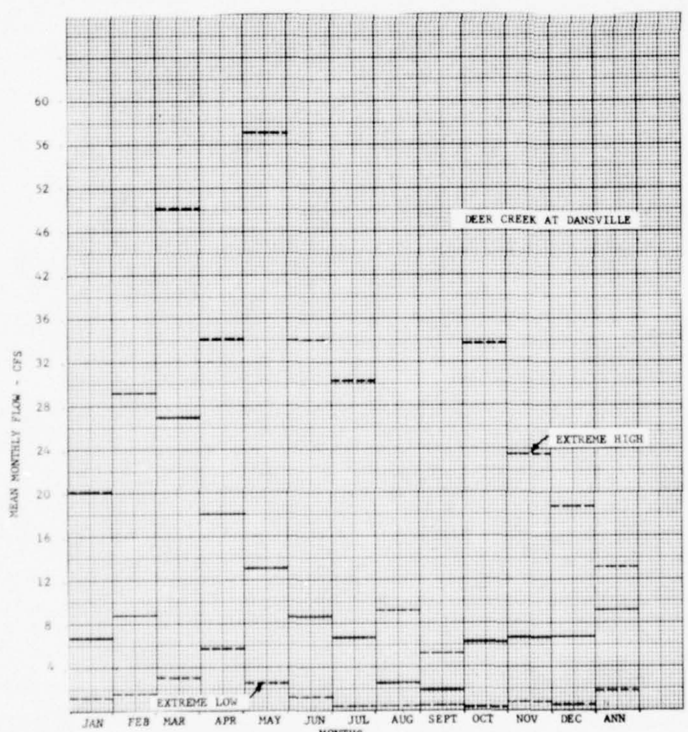
PLATE D-4B

FLOW DURATION CURVE
DEER CREEK AT DANSVILLE
Drainage Area 16.3 square miles









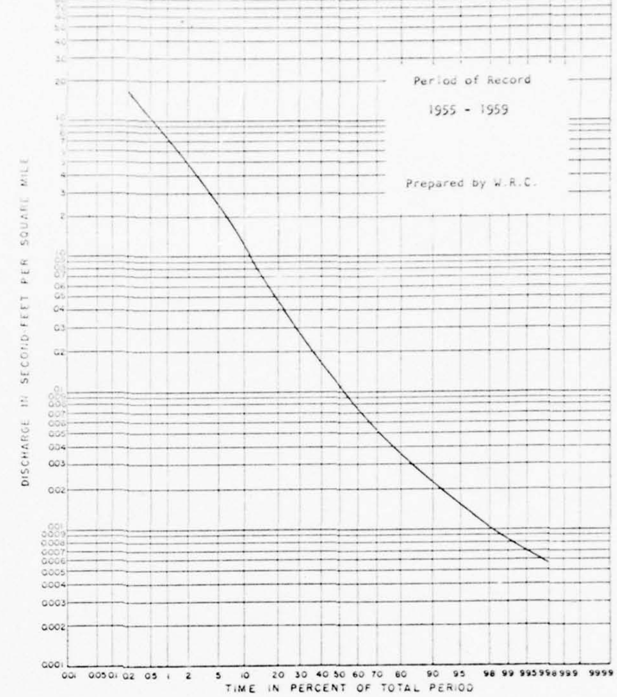
GRAND RIVER BASIN

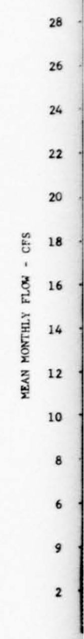
QUANTITATIVE STUDY OF STREAMFLOW DATA

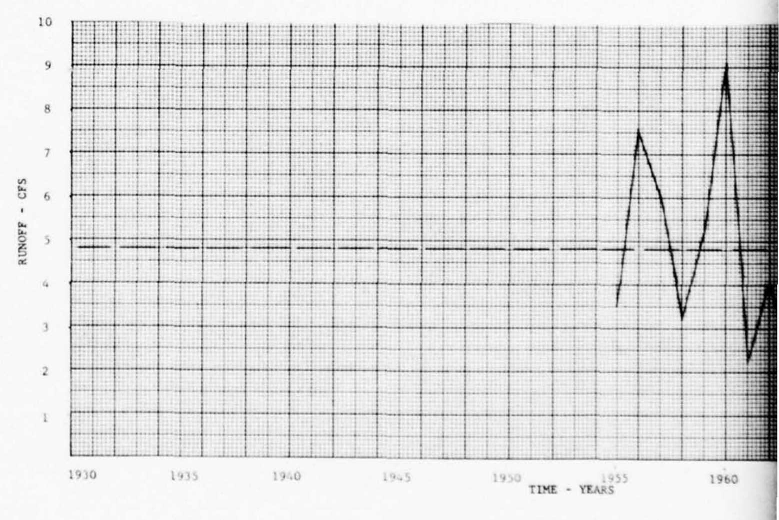
DEER CREEK AT DANSVILLE

U.S. ARMY ENGINEER DISTRICT, DETROIT

FLOW DURATION CURVE
SLOAN CREEK AT WILLIAMSTON
Drainage Area 9.34 square miles







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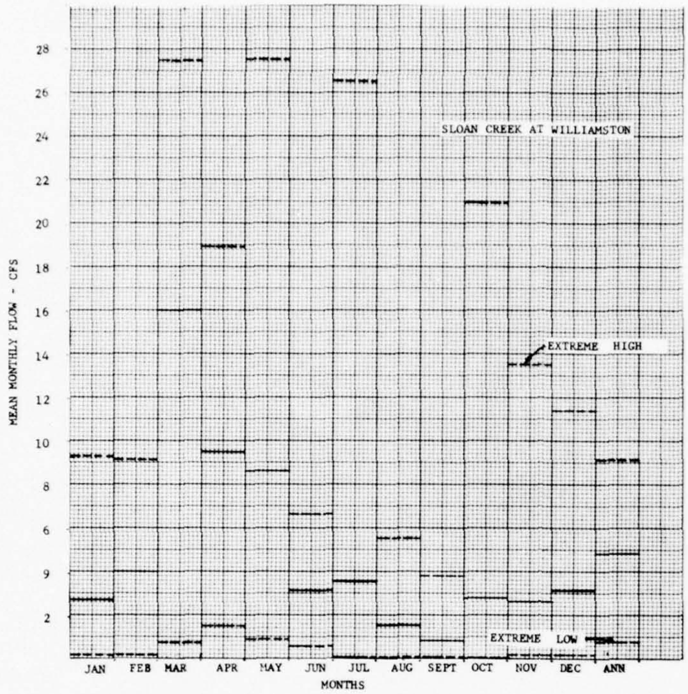
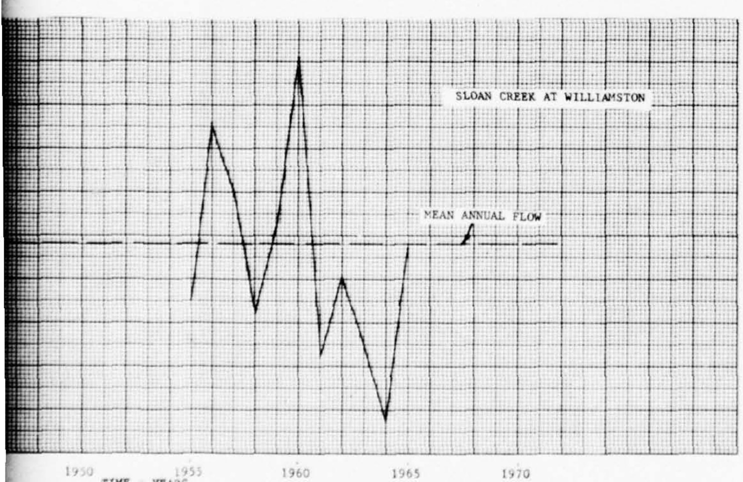


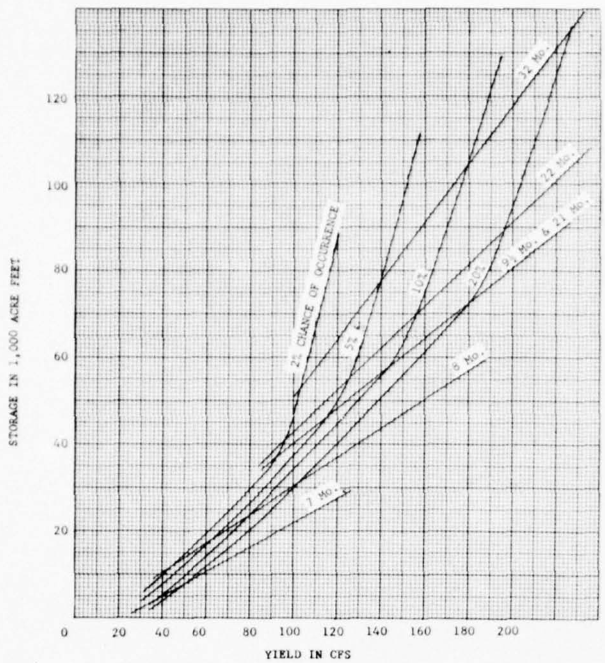


GRAND RIVER BASIN

QUANTITATIVE STUDY OF STREAMFLOW DATA

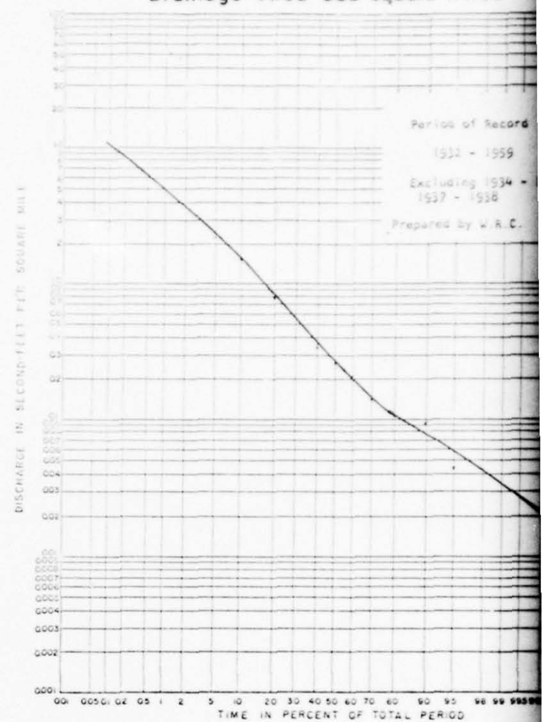
SLOAN CREEK AT WILLIAMSTON

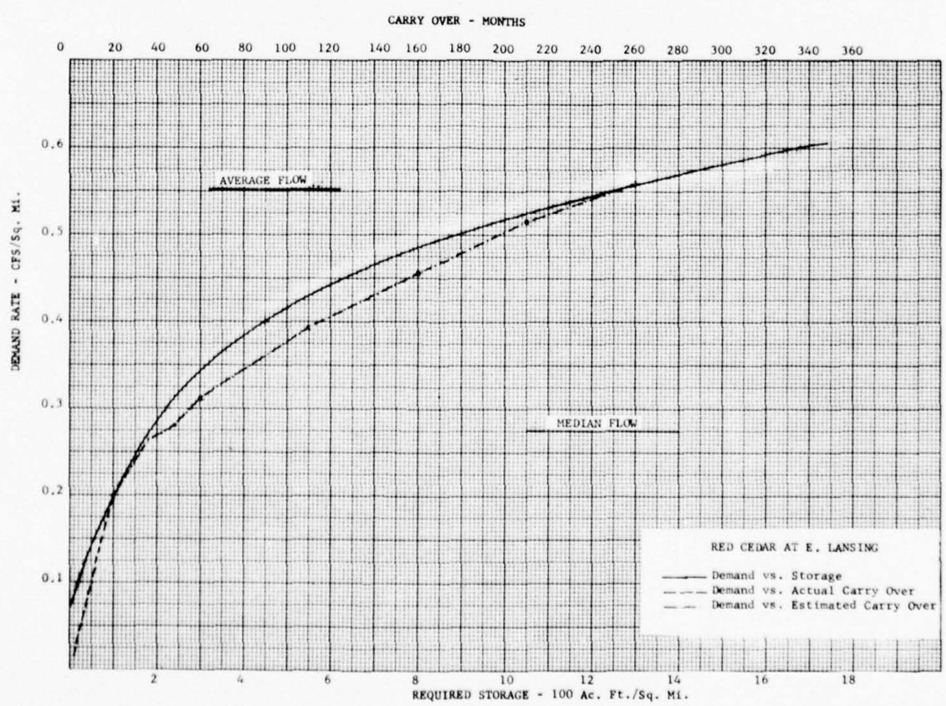
U.S. ARMY ENGINEER DISTRICT, DETROIT

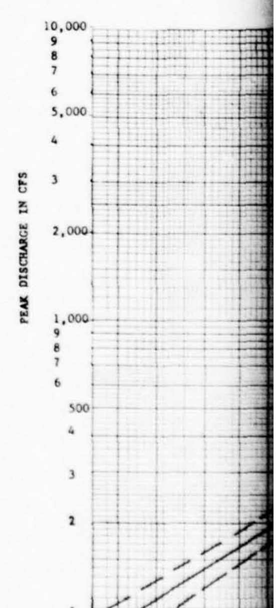


Storage - Yield Curve
RED CEDAR AT E. LANSING

FLOW DURATION CURVE
CEDAR RIVER AT EAST LANSING
Drainage Area 355 square miles







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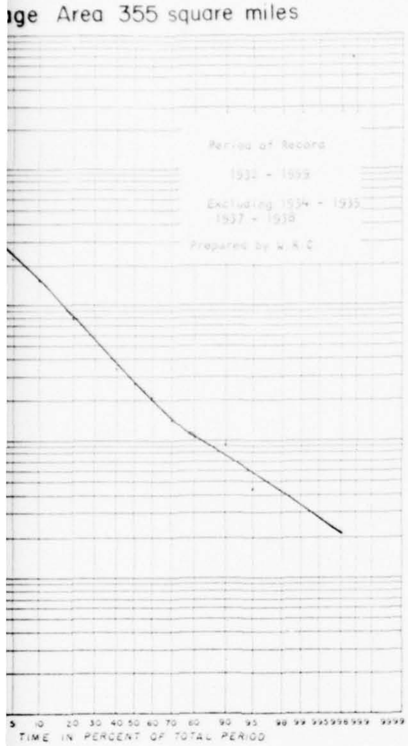
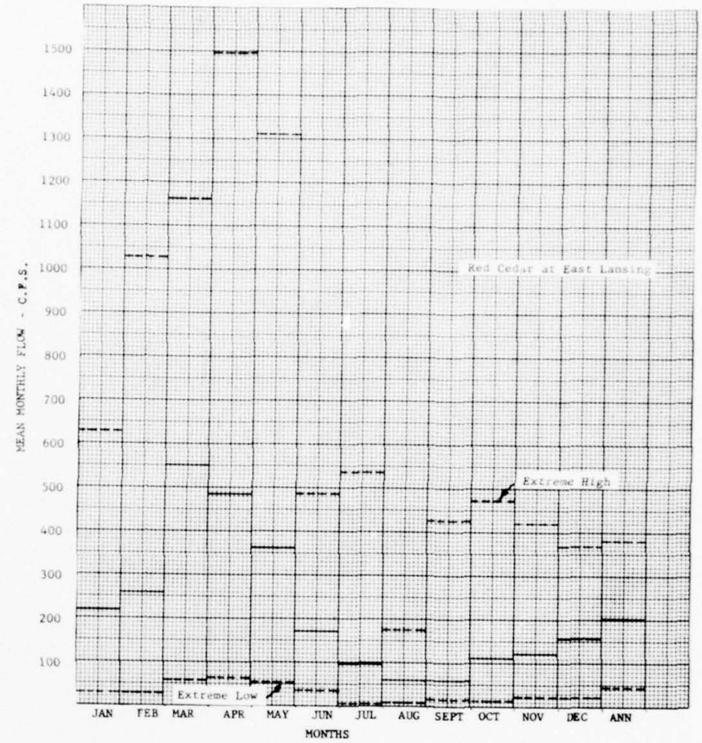
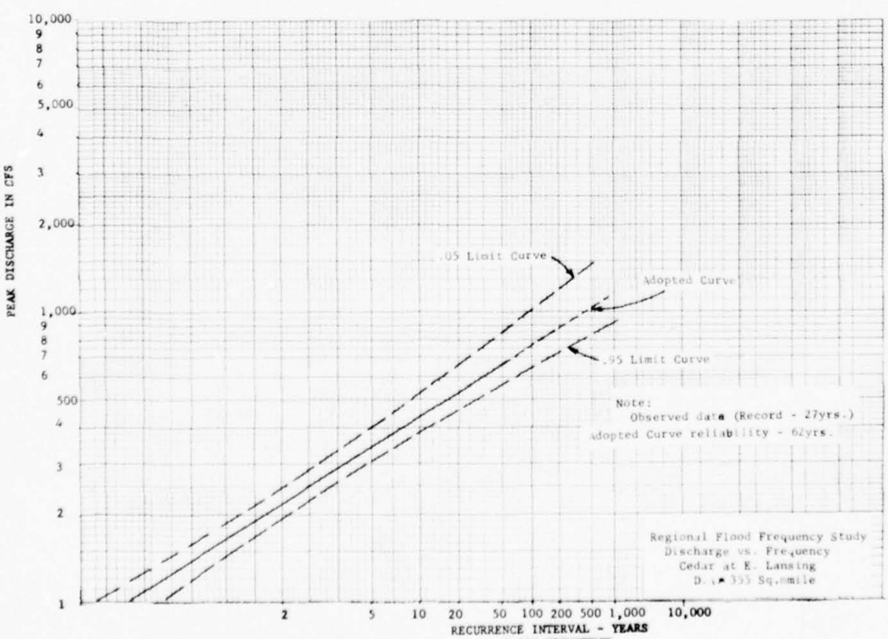
/ DURATION CURVE
RIVER AT EAST LANSING
ge Area 355 square miles





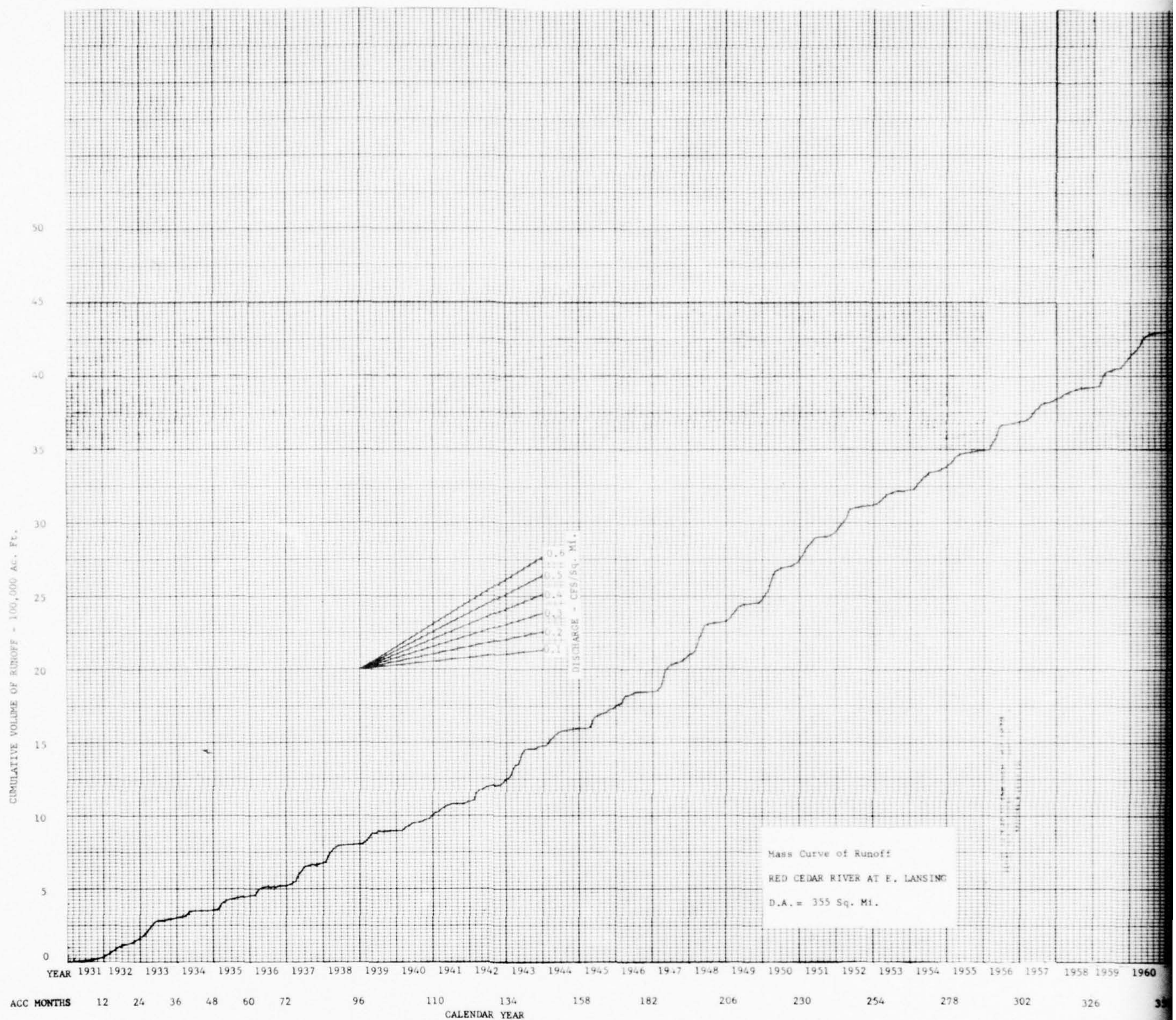


GRAND RIVER BASIN

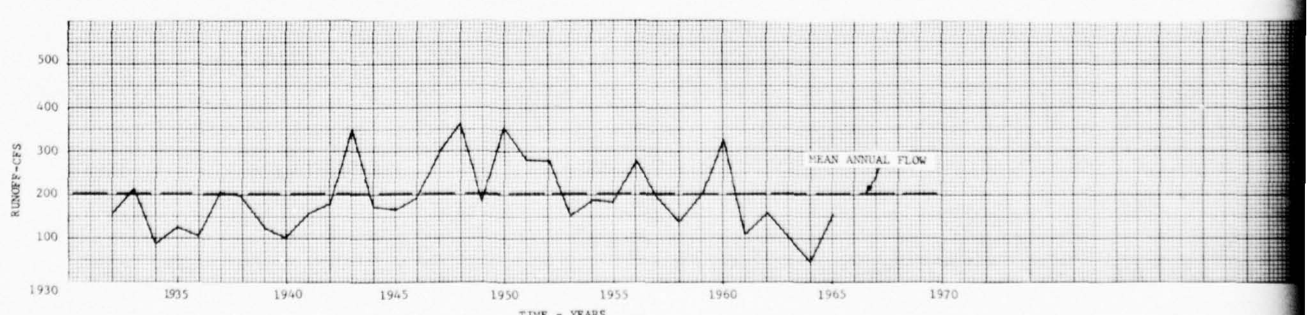
QUANTITATIVE STUDY OF STREAMFLOW DATA

RED CEDAR RIVER AT EAST LANSING

U.S. ARMY ENGINEER DISTRICT, DETROIT

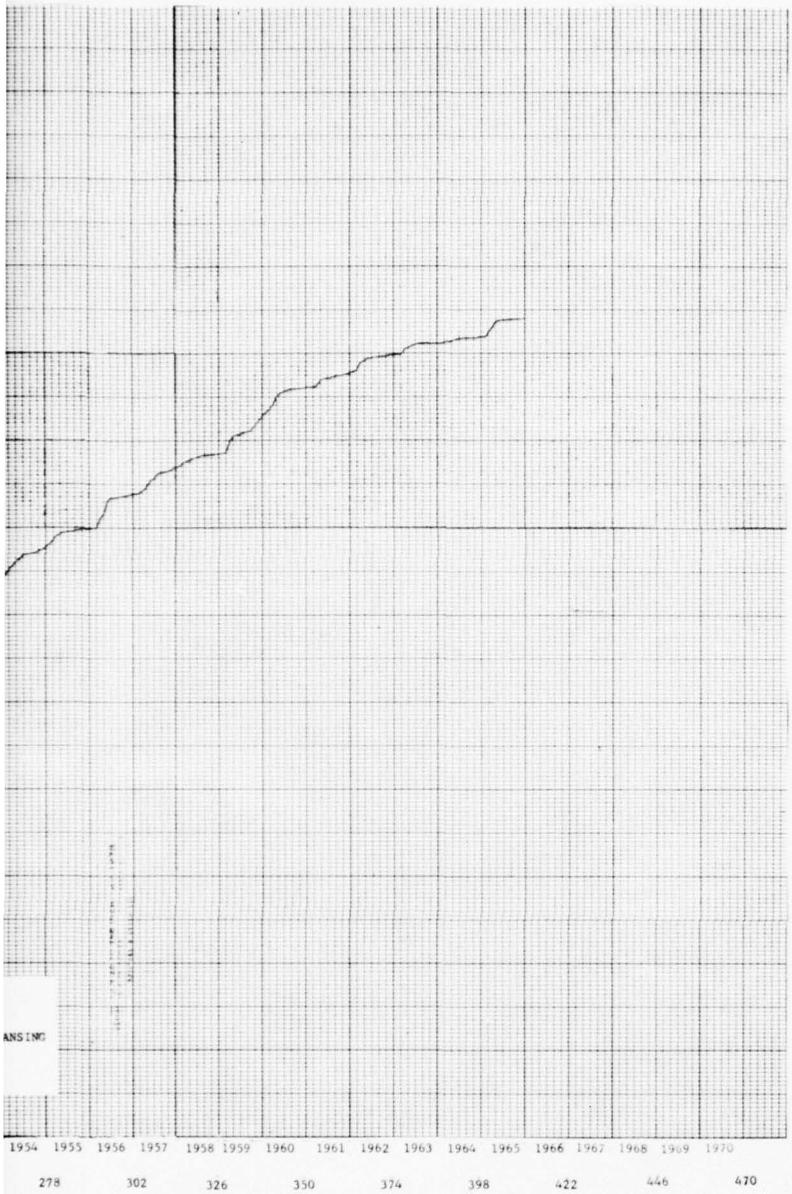


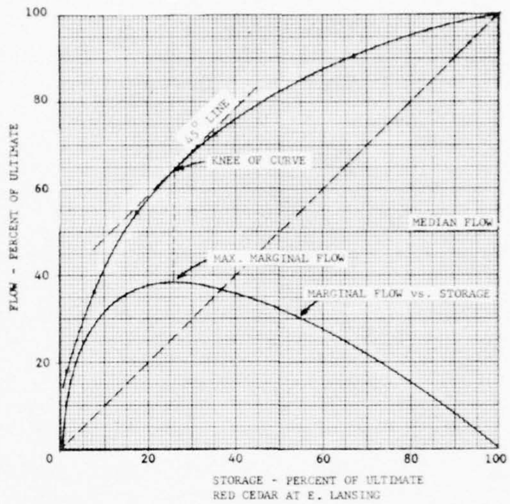
CUMULATIVE VOLUME OF RUNOFF - 100,000 Ac. Ft.
DISCHARGE - CFS/Sq. Mi.
Mass Curve of Runoff
RED CEDAR RIVER AT E. LANSING
D.A.= 355 Sq. Mi.
YEAR
ACC MONTHS
CALENDAR YEAR



RUNOFF-CFS
MEAN ANNUAL FLOW
TIME - YEARS

2





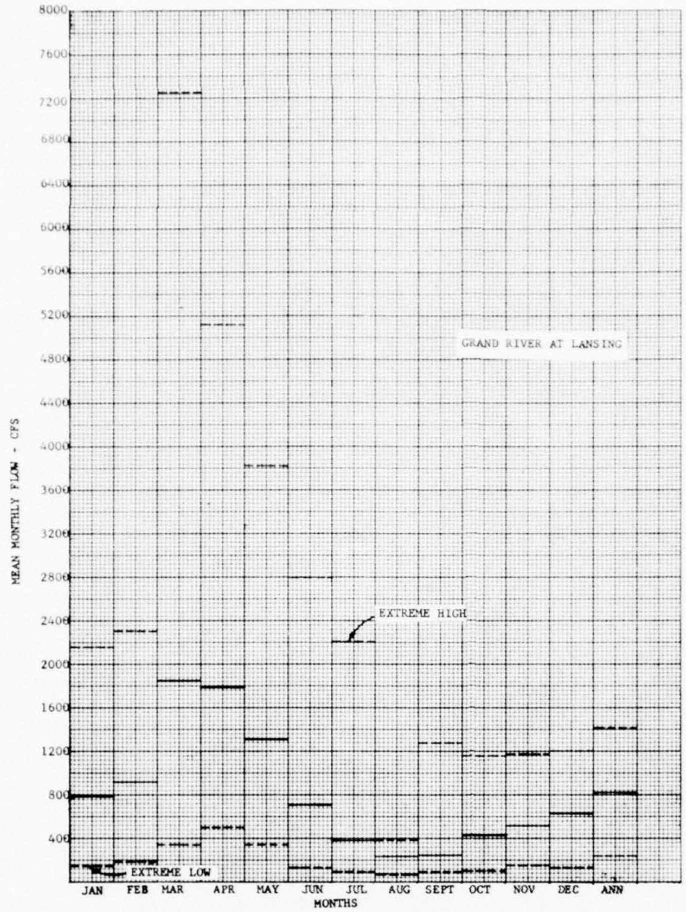
Optimum Flow - Storage Development
RED CEDAR AT E. LANSING

GRAND RIVER BASIN

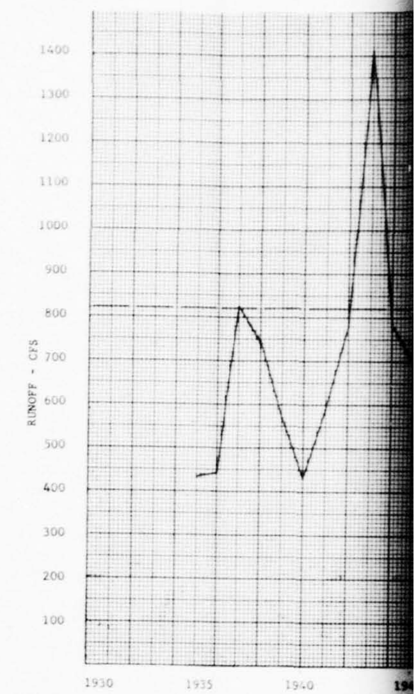
QUANTITATIVE STUDY OF
STREAMFLOW DATA

RED CEDAR RIVER
AT
EAST LANSING

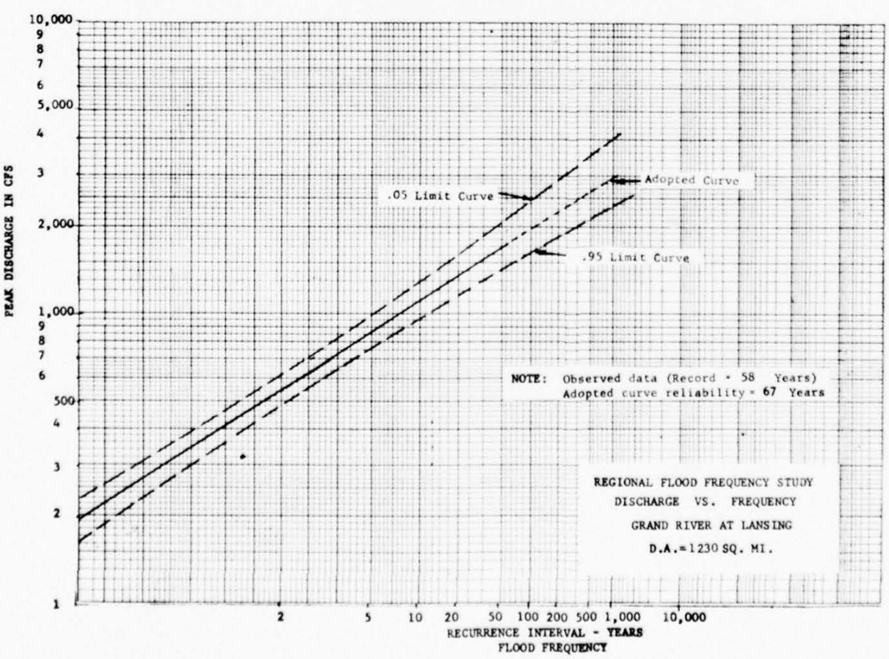
U.S. ARMY ENGINEER DISTRICT, DETROIT



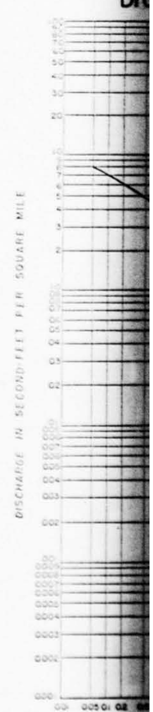
MEAN MONTHLY FLOW - CFS
GRAND RIVER AT LANSING
EXTREME HIGH
EXTREME LOW
JAN FEB MAR APR MAY JUN JUL AUG SEPT OCT NOV DEC ANN
MONTHS



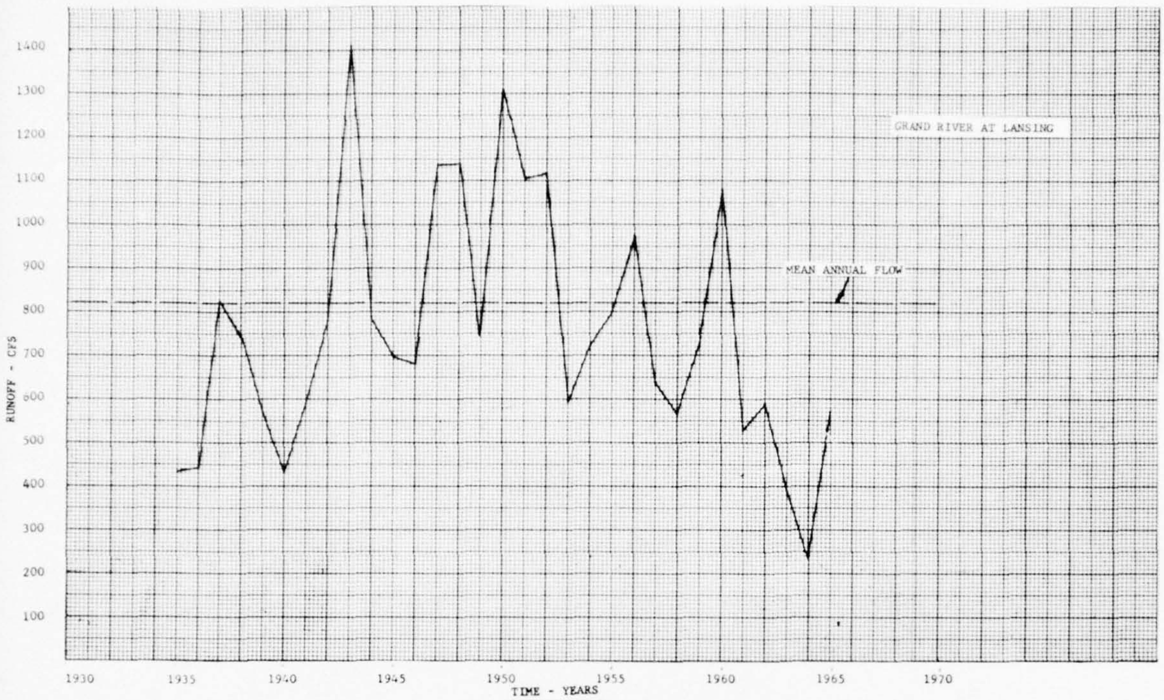
RUNOFF - CFS
1930 1935 1940



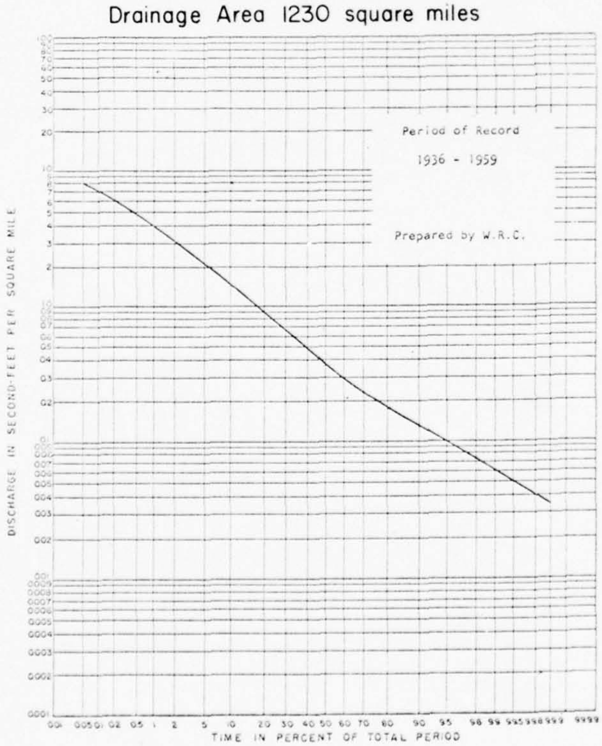
PEAK DISCHARGE IN CFS
.05 Limit Curve
Adopted Curve
.95 Limit Curve
NOTE: Observed data (Record = 58 Years)
Adopted curve reliability = 67 Years
REGIONAL FLOOD FREQUENCY STUDY
DISCHARGE VS. FREQUENCY
GRAND RIVER AT LANSING
D.A.=1230 SQ. MI.
RECURRENCE INTERVAL - YEARS
FLOOD FREQUENCY



DISCHARGE IN SECOND-FEET PER SQUARE MILE



FLOW DURATION CURVE
GRAND RIVER AT LANSING
Drainage Area 1230 square miles

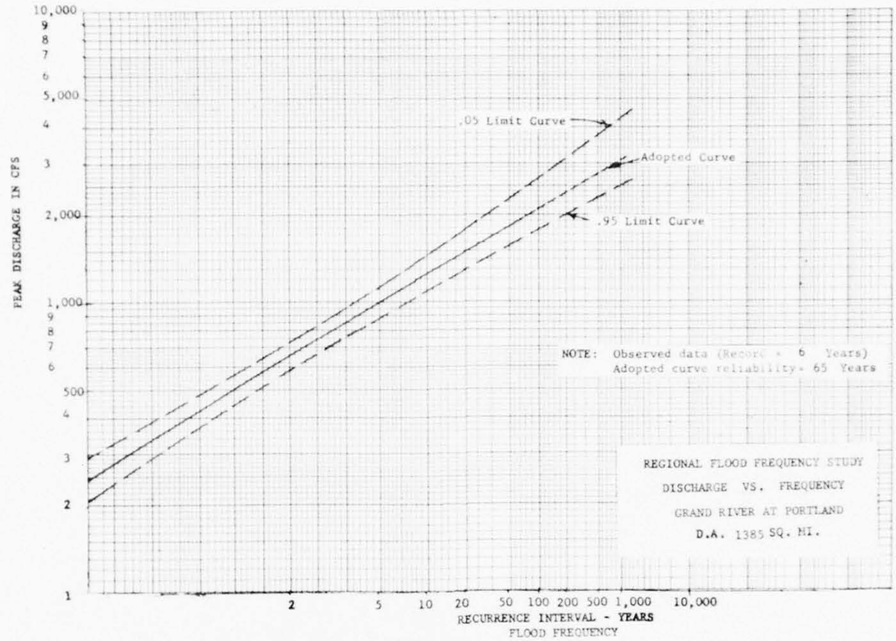


GRAND RIVER BASIN

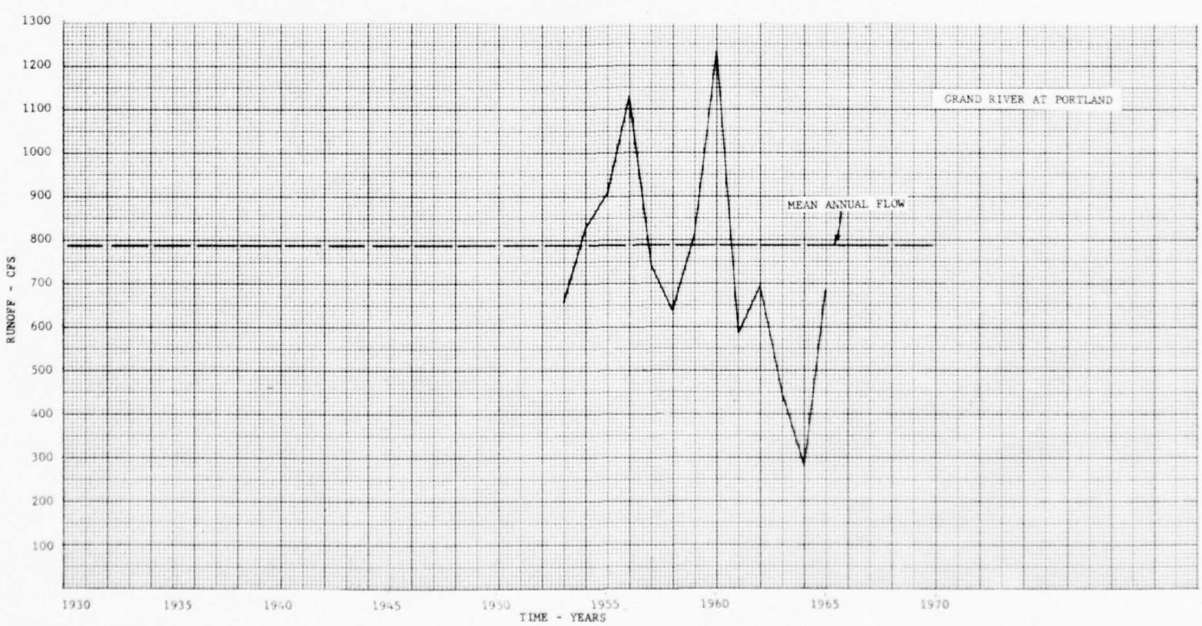
QUANTITATIVE STUDY OF STREAMFLOW DATA

GRAND RIVER AT LANSING

U.S. ARMY ENGINEER DISTRICT, DETROIT



FLOOD FREQUENCY



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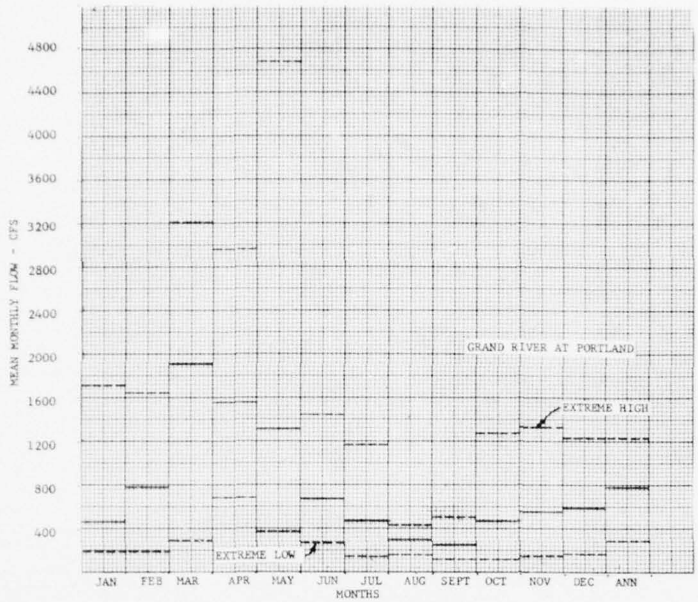
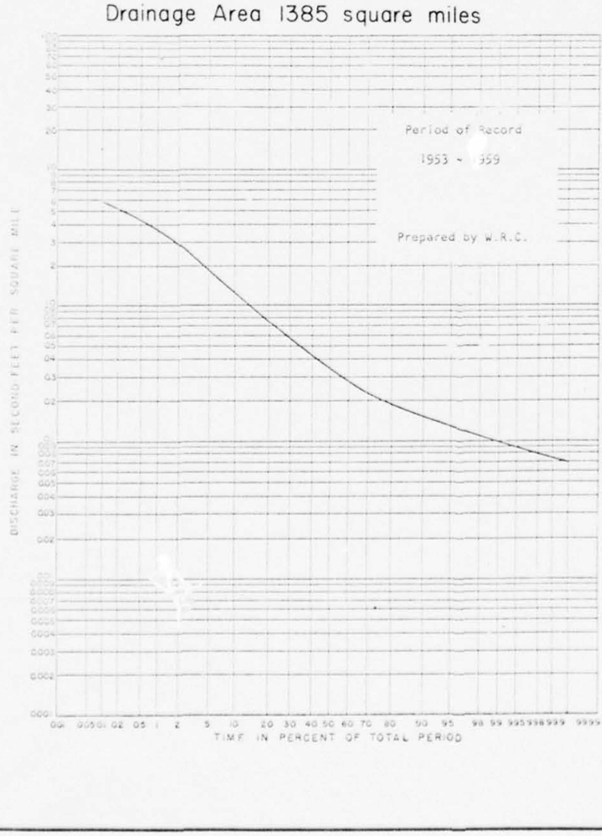
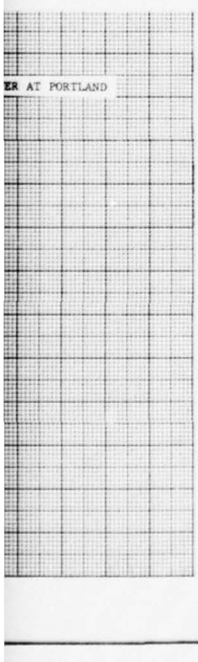


FLOW DURATION CURVE
GRAND RIVER AT PORTLAND
Drainage Area 1385 square miles



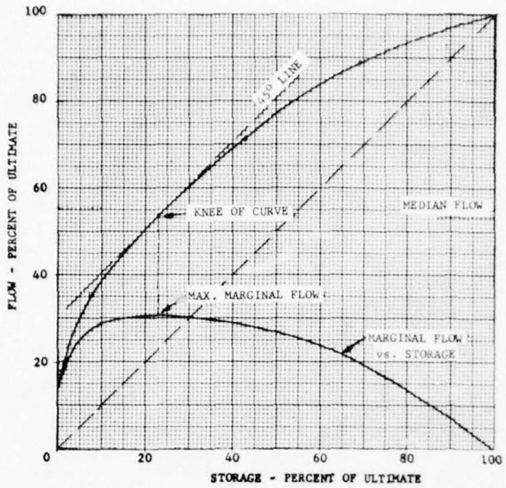


GRAND RIVER BASIN

QUANTITATIVE STUDY OF STREAMFLOW DATA

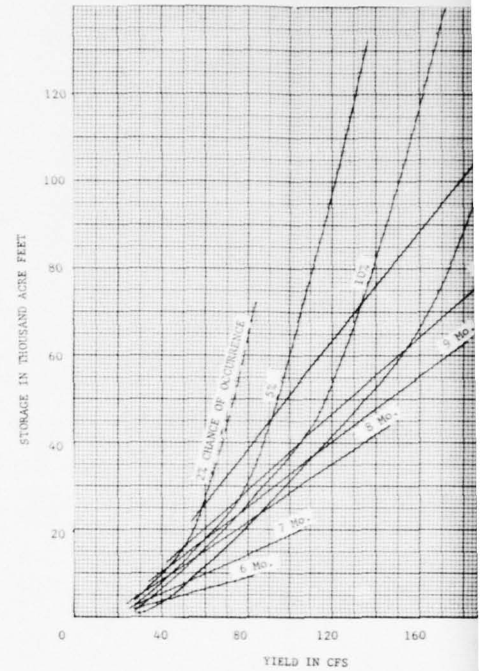
GRAND RIVER AT PORTLAND

U.S. ARMY ENGINEER DISTRICT, DETROIT



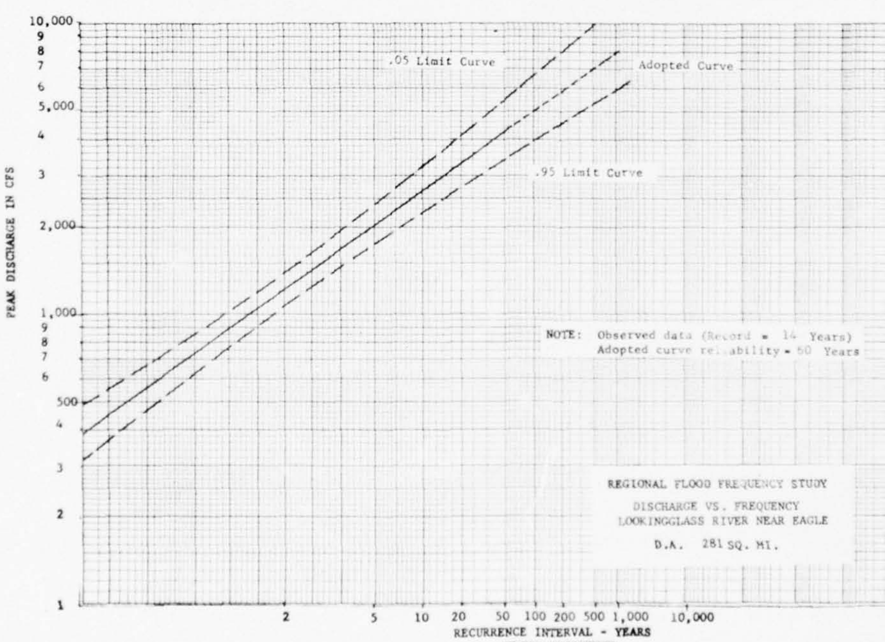
Optimum Flow - Storage Development

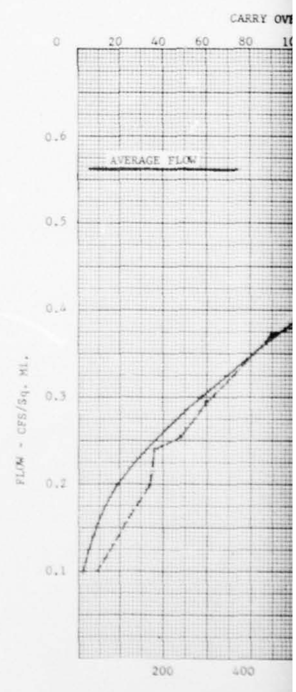
LOOKINGGLASS RIVER NEAR EAGLE

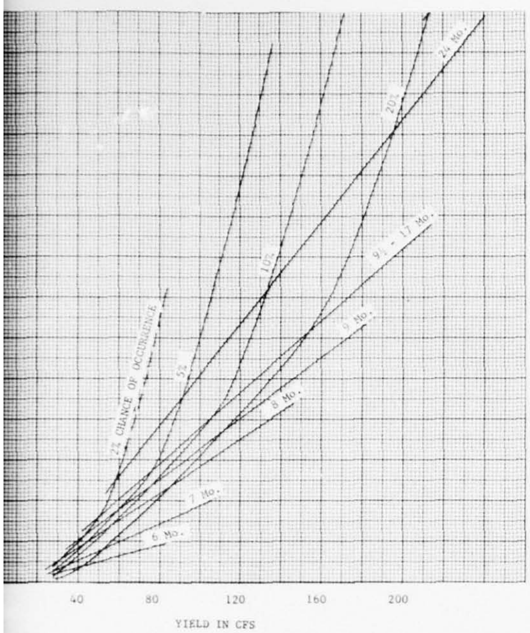


Storage - Yield Curve

LOOKINGGLASS RIVER NEAR EAGLE

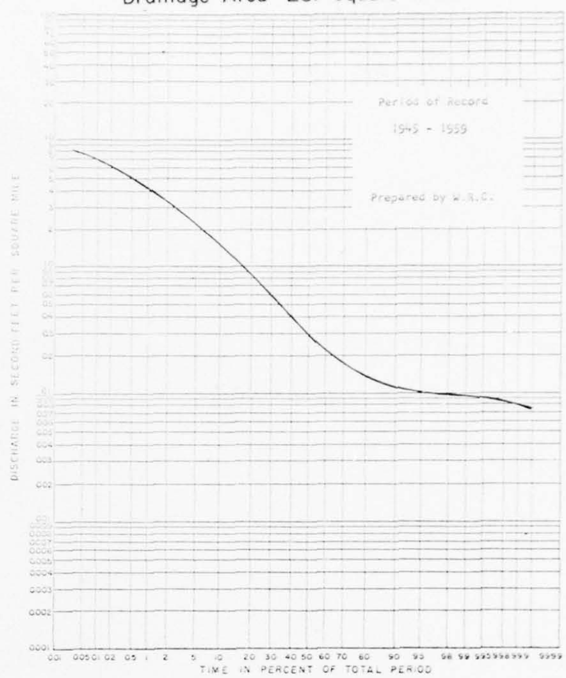


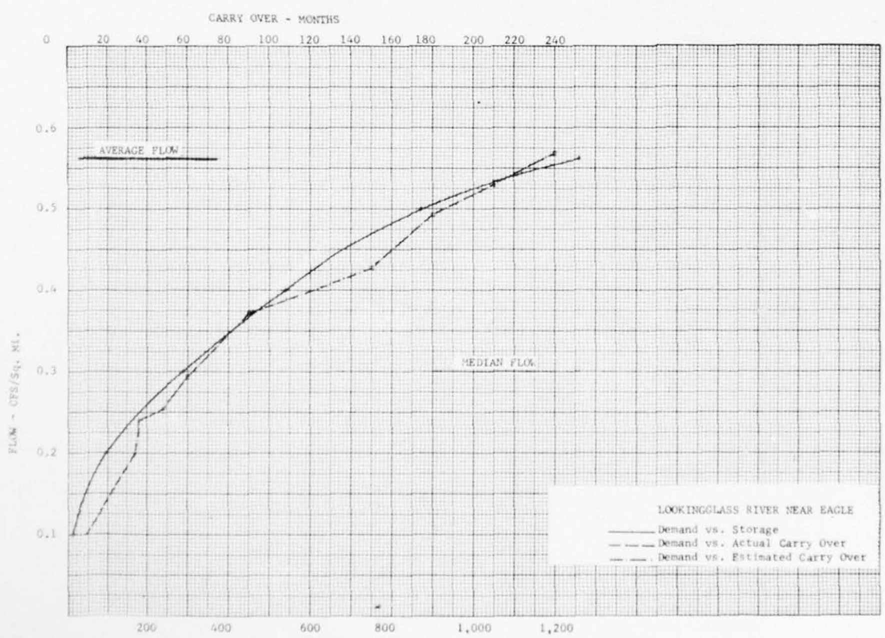




Storage - Yield Curve
LOOKINGGLASS RIVER NEAR EAGLE

FLOW DURATION CURVE
LOOKINGGLASS RIVER NEAR EAGLE
Drainage Area 281 square miles



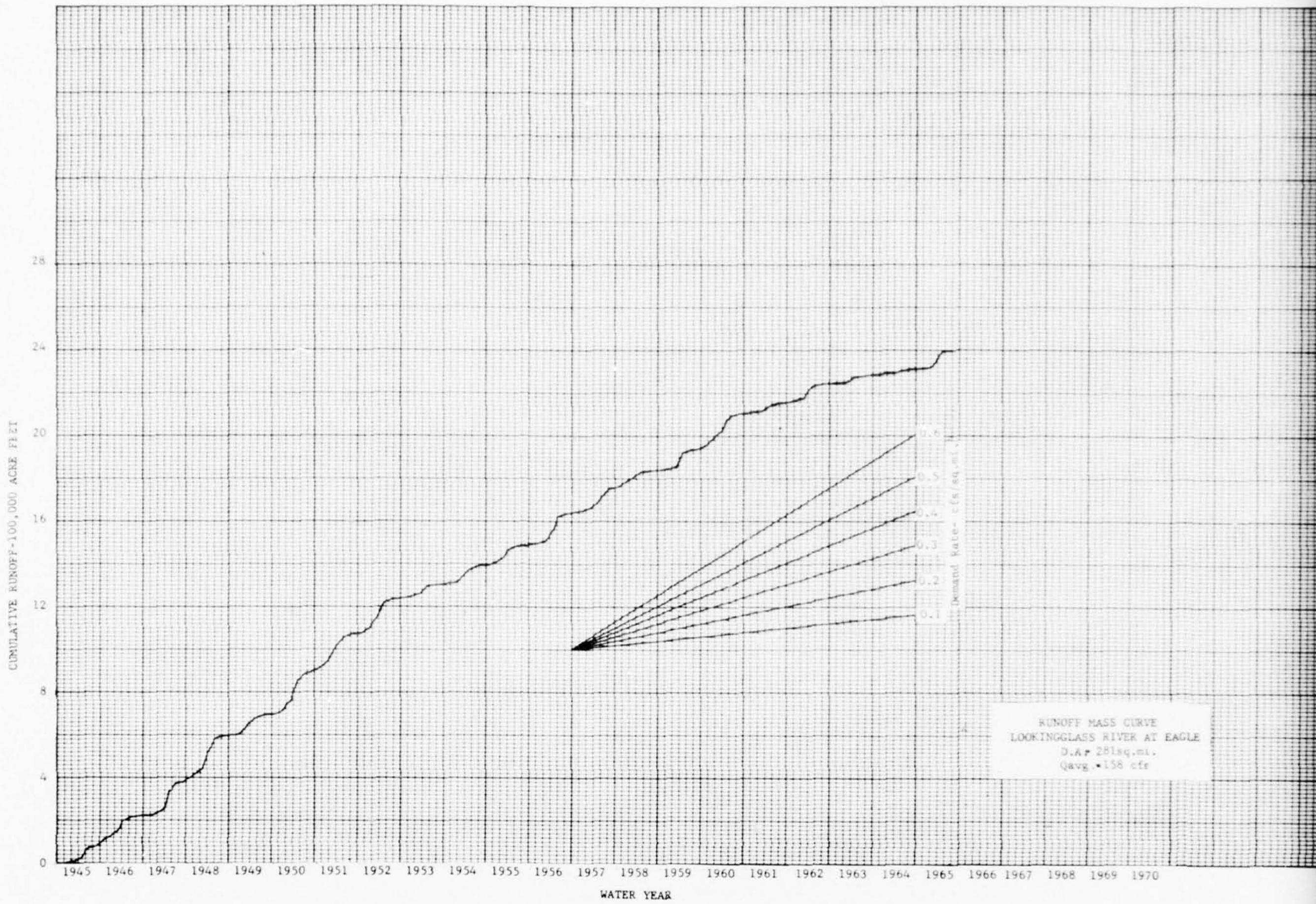


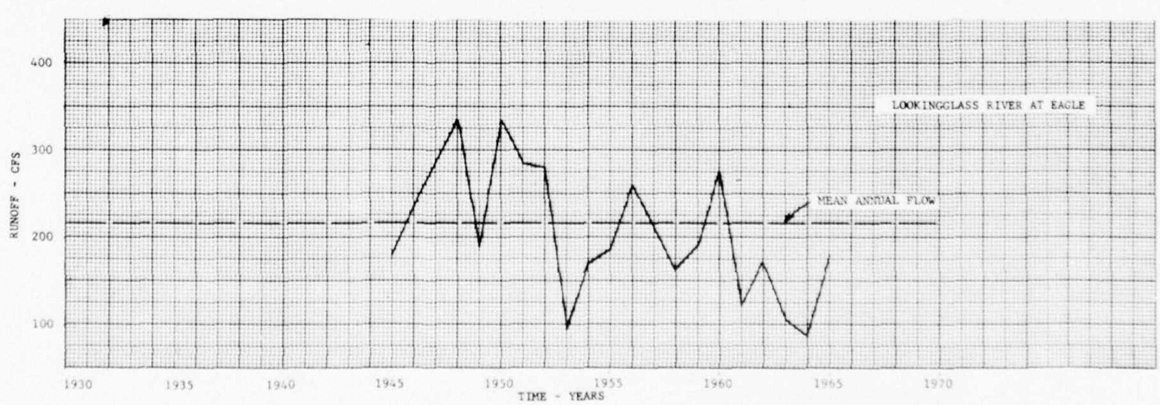
GRAND RIVER BASIN

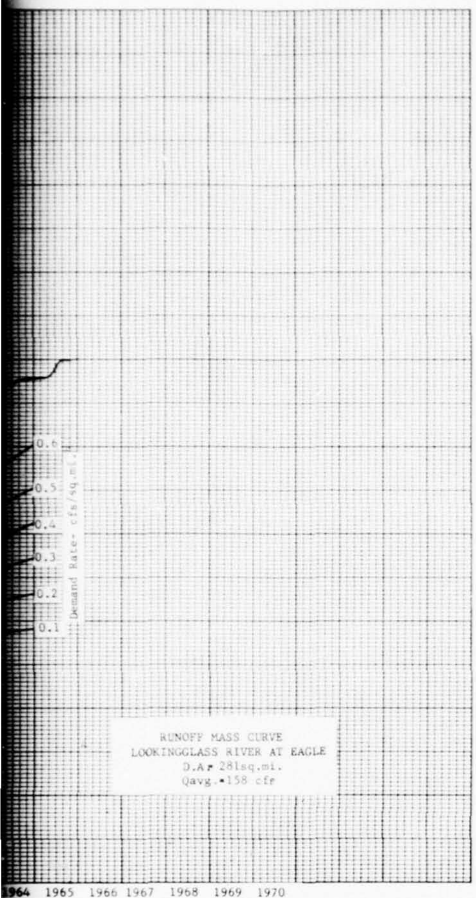
QUANTITATIVE STUDY OF STREAMFLOW DATA

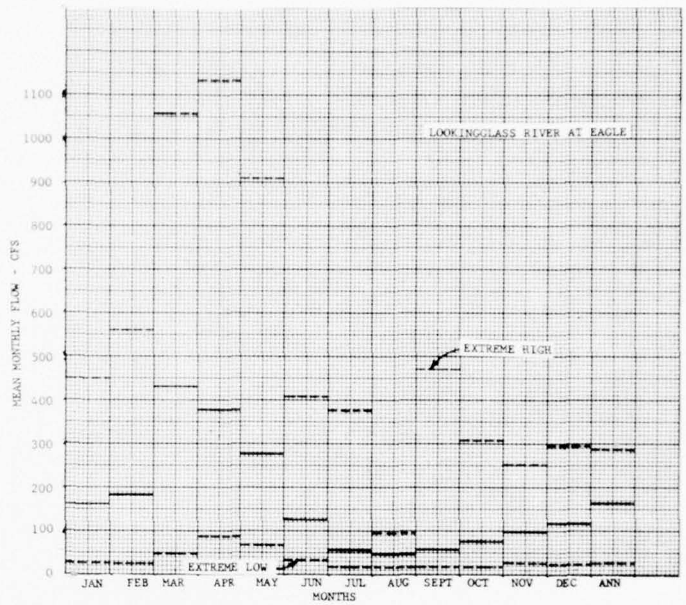
LOOKINGGLASS RIVER NEAR EAGLE

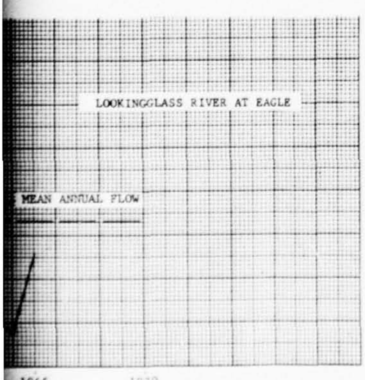
U.S. ARMY ENGINEER DISTRICT, DETROIT


RUNOFF MASS CURVE
LOOKINGGLASS RIVER AT EAGLE
D.A.= 281sq.mi.
Qavg.=158 cfs
Demand Rate- cfs/sq.mi.
0.6
0.5
0.4
0.3
0.2
0.1
CUMULATIVE RUNOFF-100,000 ACRE FEET
0
4
8
12
16
20
24
28
1945 1946 1947 1948 1949 1950 1951 1952 1953 1954 1955 1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970
WATER YEAR


LOOKINGGLASS RIVER AT EAGLE
MEAN ANNUAL FLOW
RUNOFF - CFS
100
200
300
400
1930 1935 1940 1945 1950 1955 1960 1965 1970
TIME - YEARS







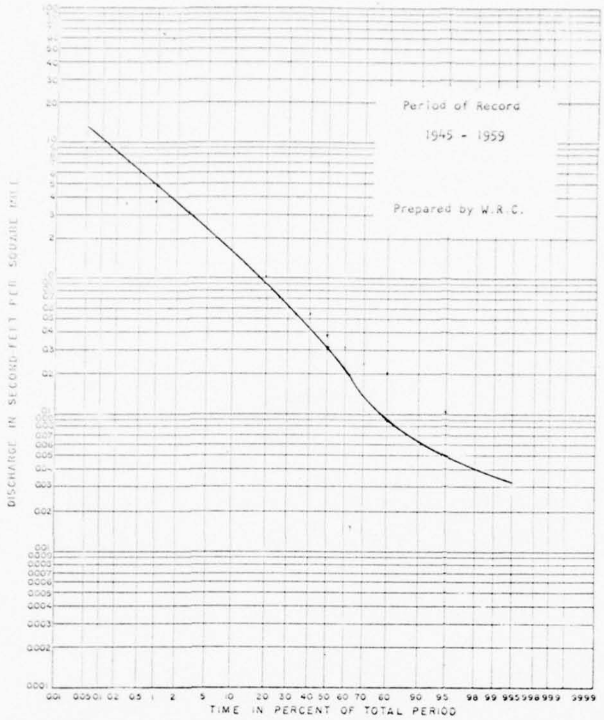
GRAND RIVER BASIN

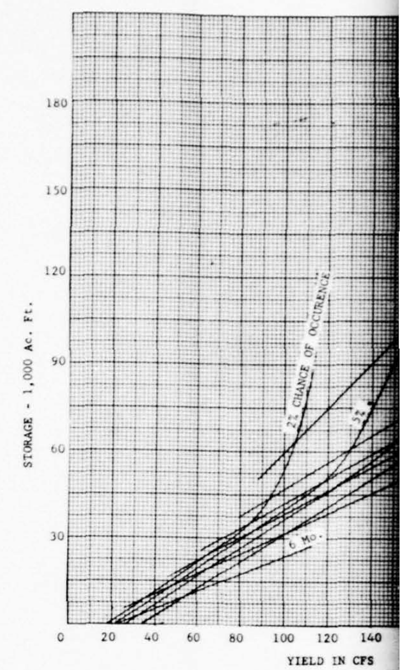
QUANTITATIVE STUDY OF STREAMFLOW DATA

LOOKINGGLASS RIVER NEAR EAGLE

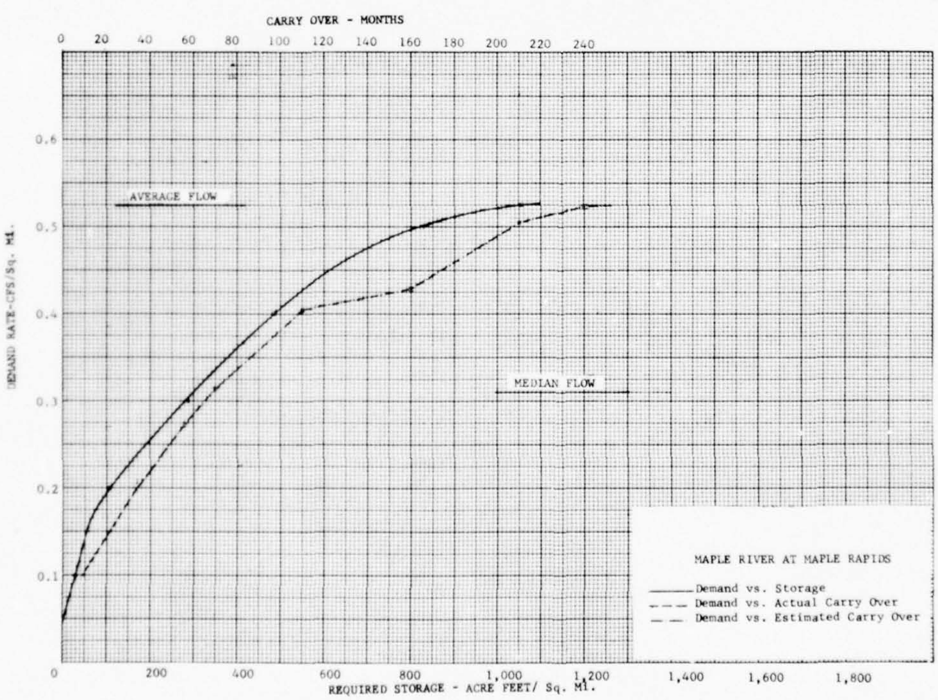
U.S. ARMY ENGINEER DISTRICT, DETROIT

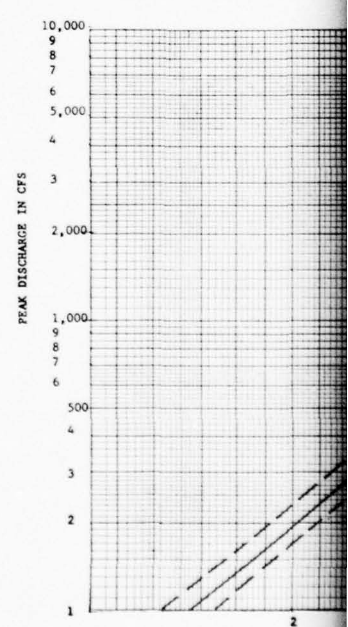
FLOW DURATION CURVE
MAPLE RIVER AT MAPLE RAPIDS
Drainage Area 434 square miles





Storage - Yield Cur
MAPLE RIVER AT MAP





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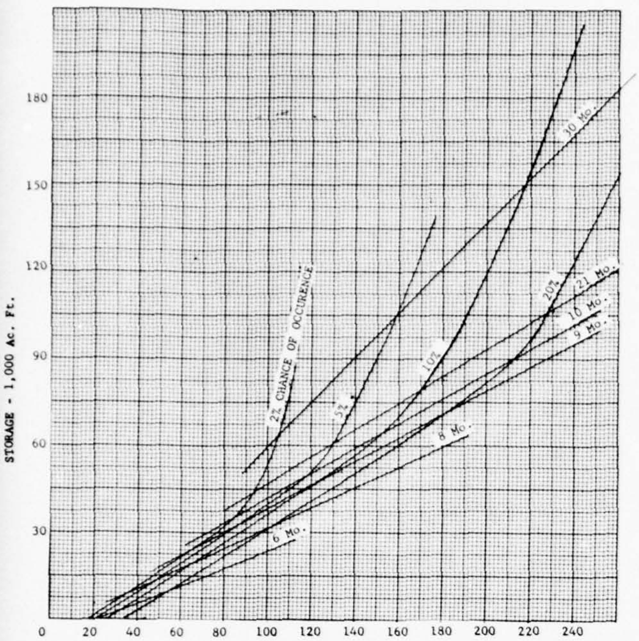
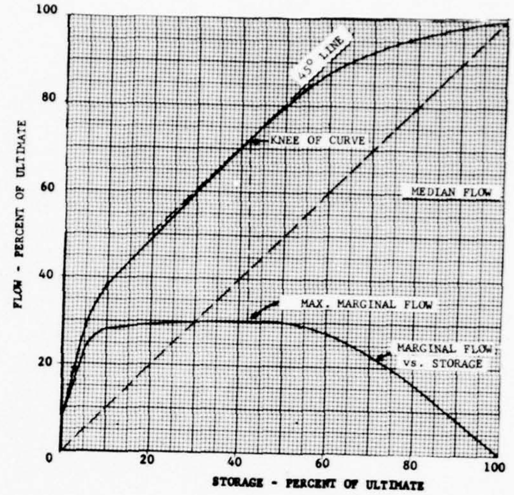
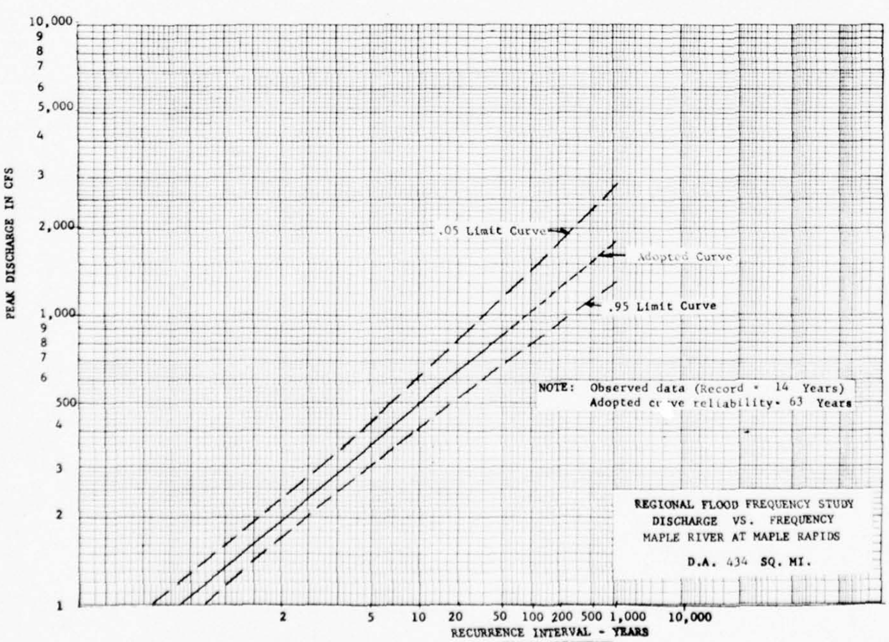


Storage - Yield Curve
MAPLE RIVER AT MAPLE RAPIDS



Optimum Flow - Storage Development
LOOKINGGLASS RIVER NEAR EAGLE



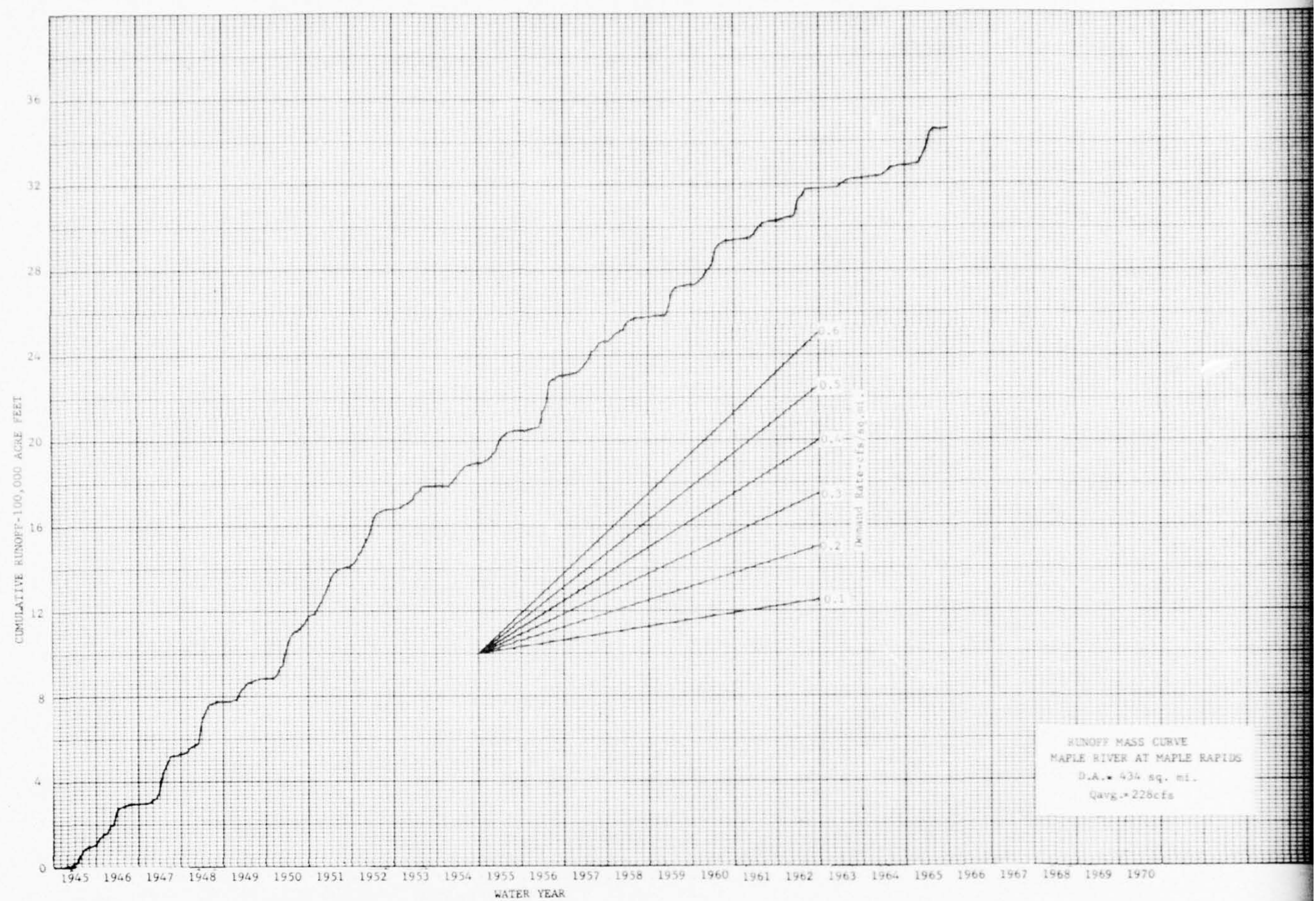
FLOOD FREQUENCY

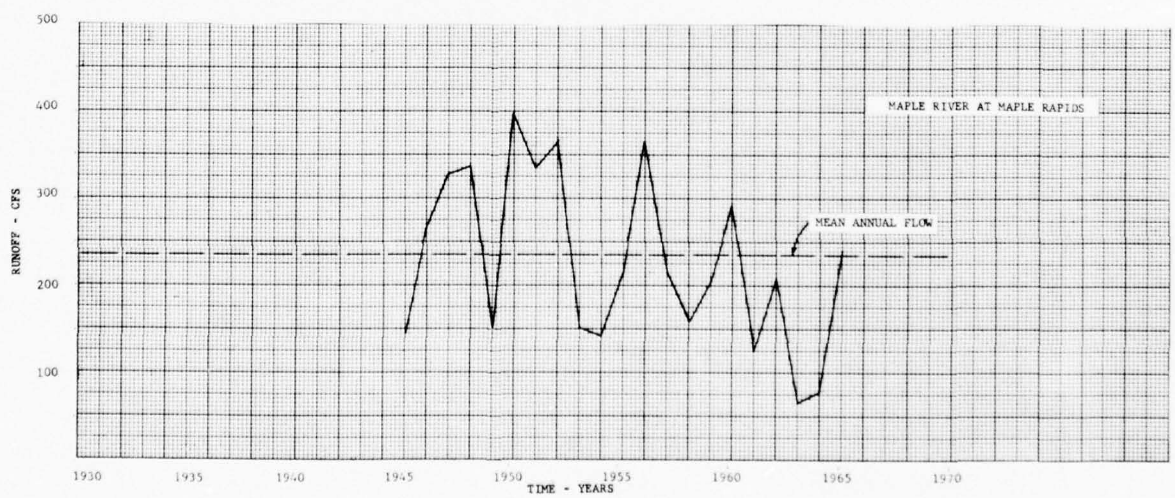
GRAND RIVER BASIN

QUANTITATIVE STUDY OF STREAMFLOW DATA

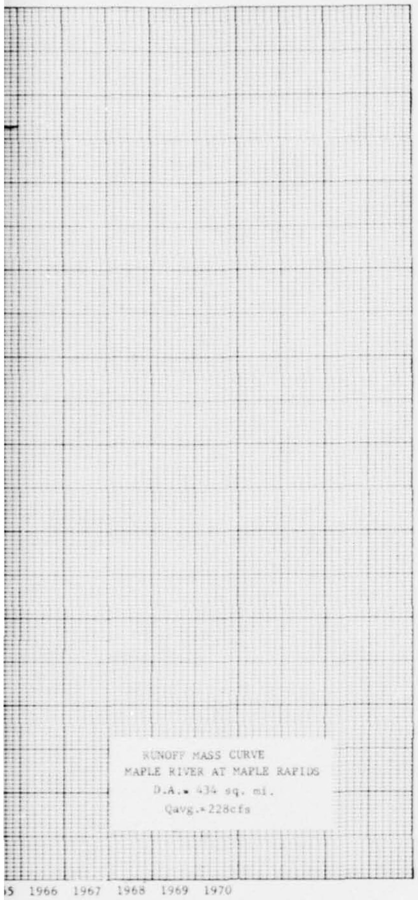
MAPLE RIVER AT MAPLE RAPIDS

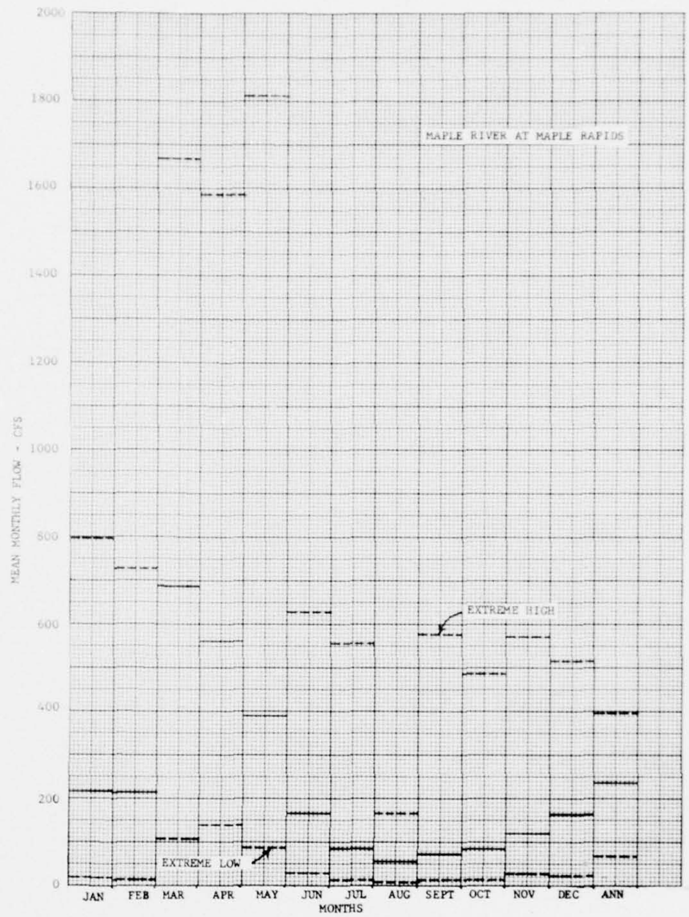
U.S. ARMY ENGINEER DISTRICT, DETROIT

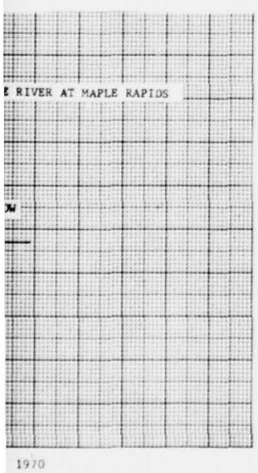

RUNOFF MASS CURVE
MAPLE RIVER AT MAPLE RAPIDS
D.A.= 434 sq. mi.
Qavg.=228cfs
Demand Rate-cfs/sq.mi.
0.6
0.5
0.4
0.3
0.2
0.1
CUMULATIVE RUNOFF-100,000 ACRE FEET
0
4
8
12
16
20
24
28
32
36
1945 1946 1947 1948 1949 1950 1951 1952 1953 1954 1955 1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970
WATER YEAR


MAPLE RIVER AT MAPLE RAPIDS
MEAN ANNUAL FLOW
RUNOFF - CFS
100
200
300
400
500
1930
1935
1940
1945
1950
1955
1960
1965
1970
TIME - YEARS

2





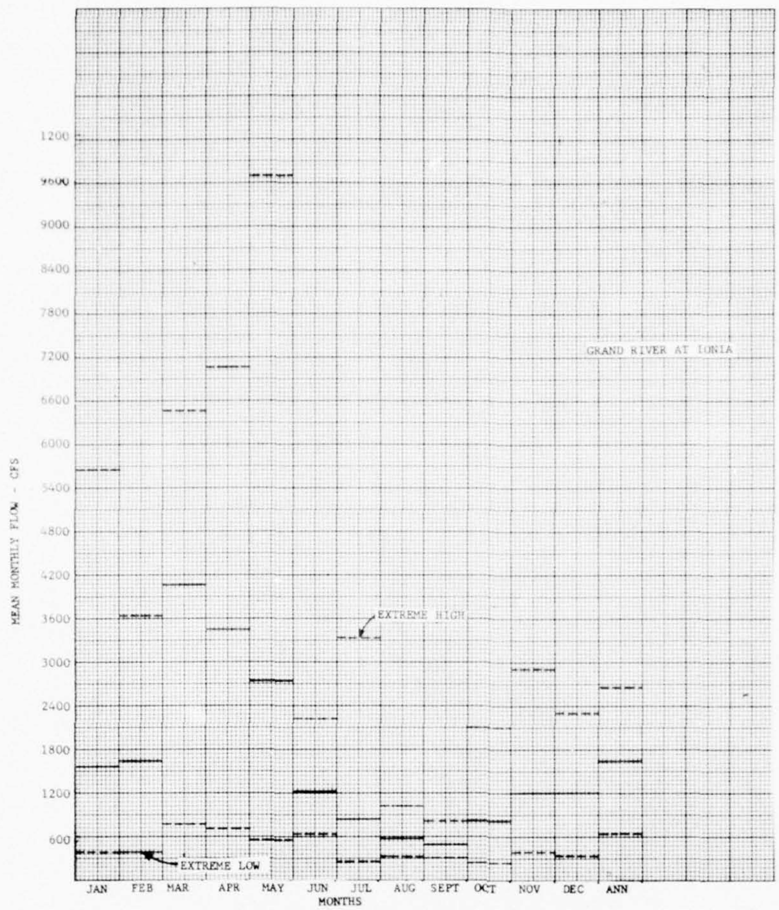


GRAND RIVER BASIN

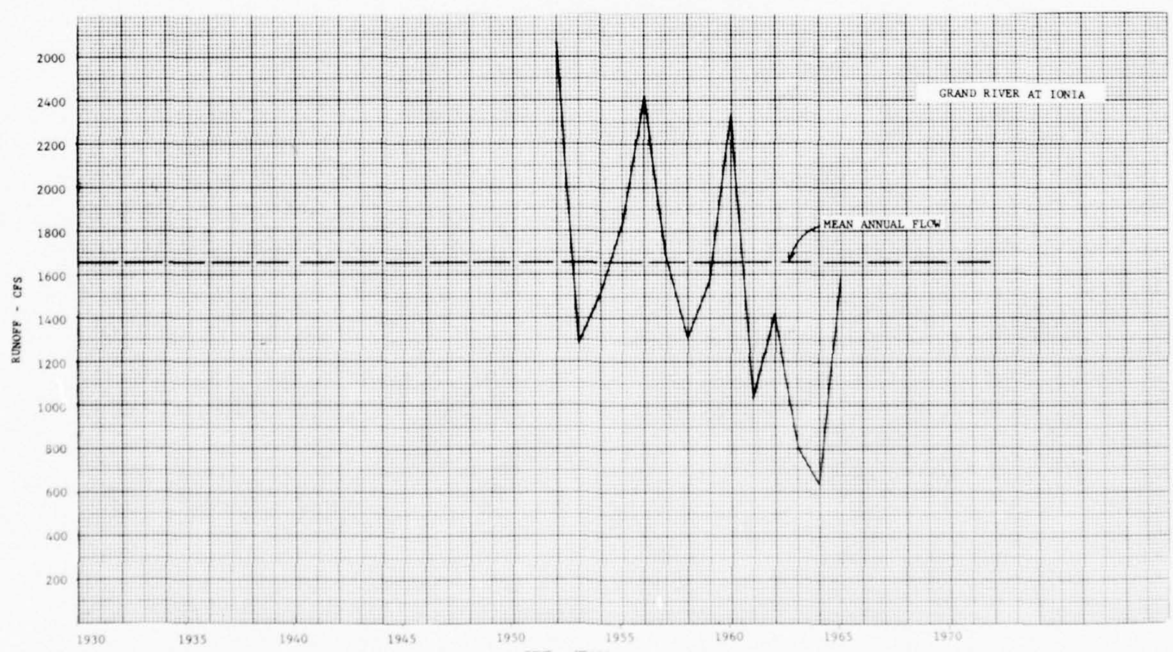
QUANTITATIVE STUDY OF STREAMFLOW DATA

MAPLE RIVER AT MAPLE RAPIDS

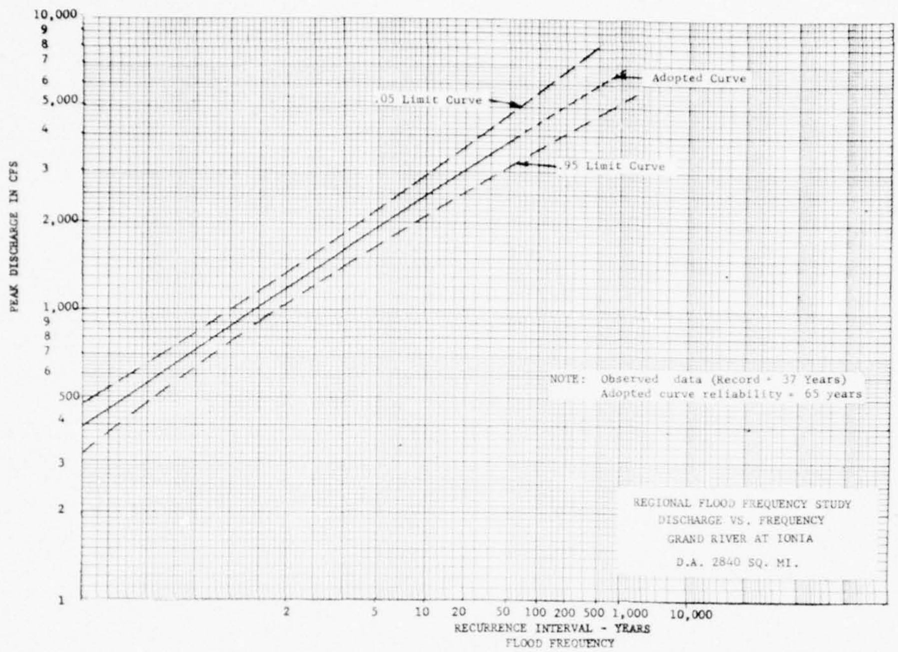
U.S. ARMY ENGINEER DISTRICT, DETROIT


GRAND RIVER AT IONIA
EXTREME HIGH
EXTREME LOW
MEAN MONTHLY FLOW - CFS
JAN FEB MAR APR MAY JUN JUL AUG SEPT OCT NOV DEC ANN
MONTHS

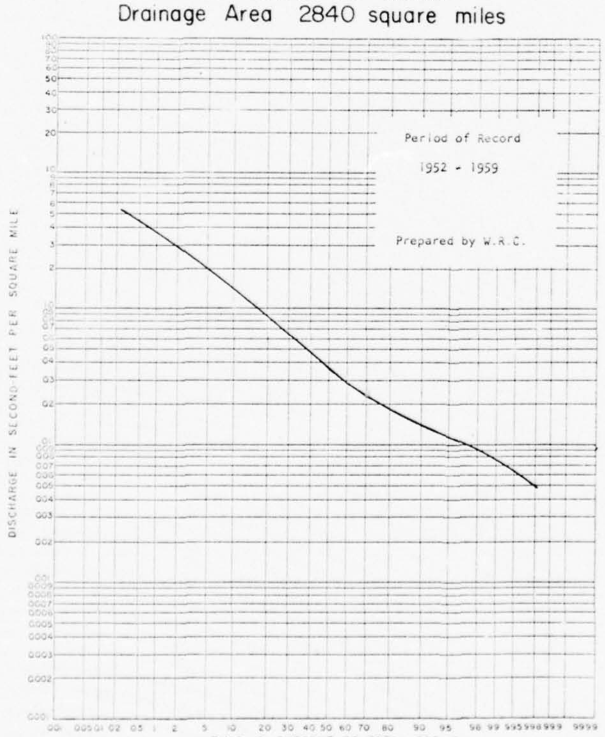

PEAK DISCHARGE IN CFS
DISCHARGE IN SECOND-FEET PER SQUARE MILE


GRAND RIVER AT IONIA
MEAN ANNUAL FLOW
RUNOFF - CFS
TIME - YEARS

2



FLOW DURATION CURVE
GRAND RIVER AT IONIA
Drainage Area 2840 square miles



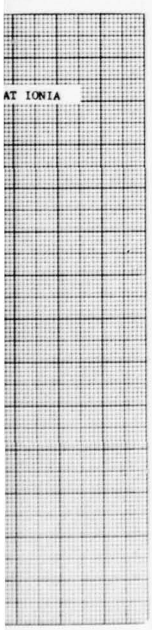


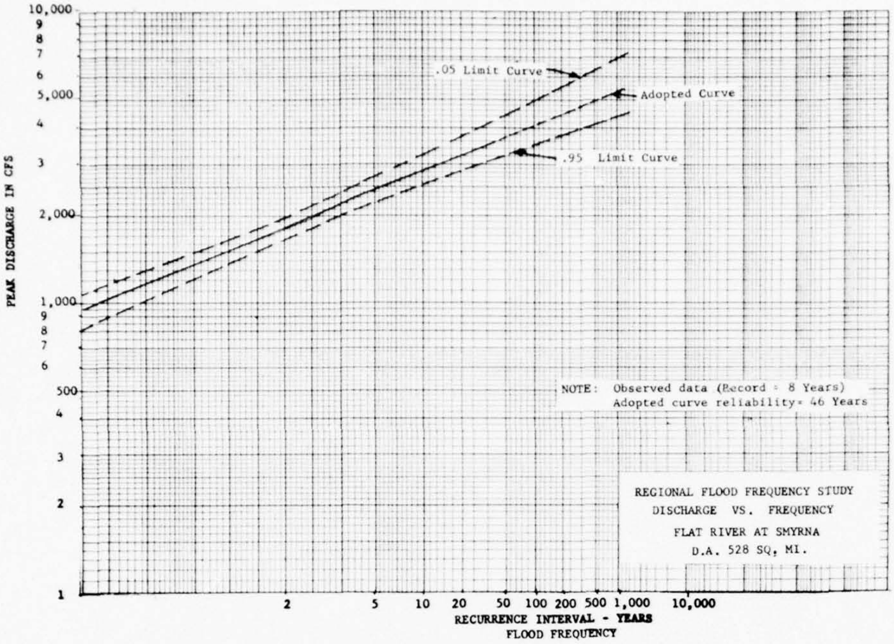
FIGURE NO. D-10

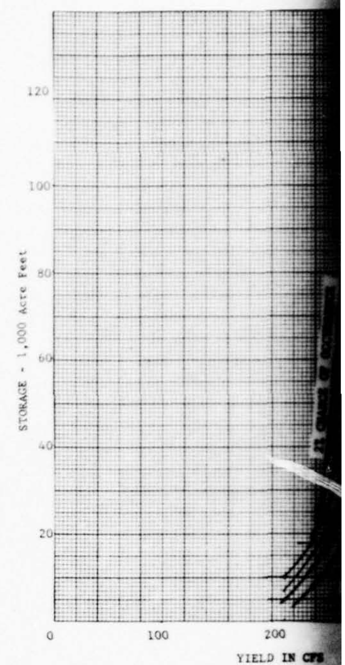
GRAND RIVER BASIN

QUANTITATIVE STUDY OF STREAMFLOW DATA

GRAND RIVER AT IONIA

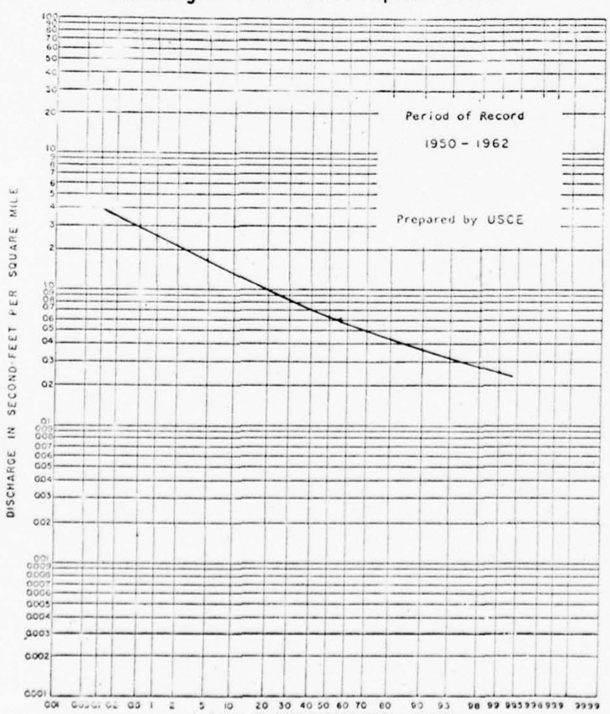
U.S. ARMY ENGINEER DISTRICT, DETROIT

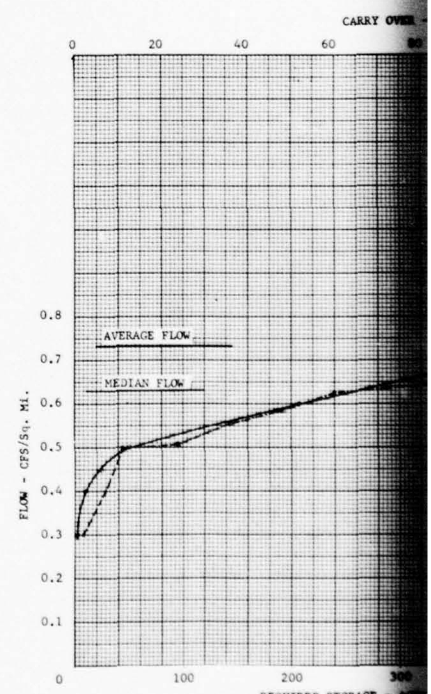


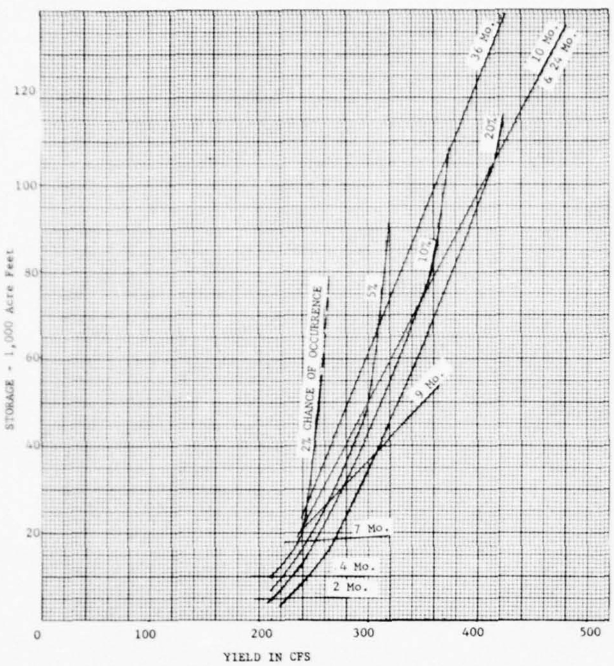


Storage - Yield
FLAT RIVER AT

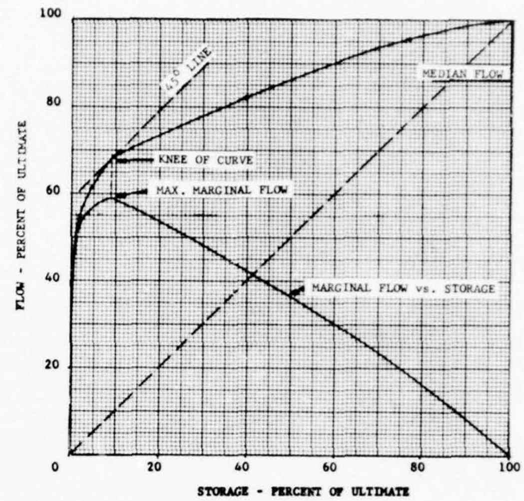
FLOW DURATION CURVE
FLAT RIVER AT SMYRNA
Drainage Area 528 square miles



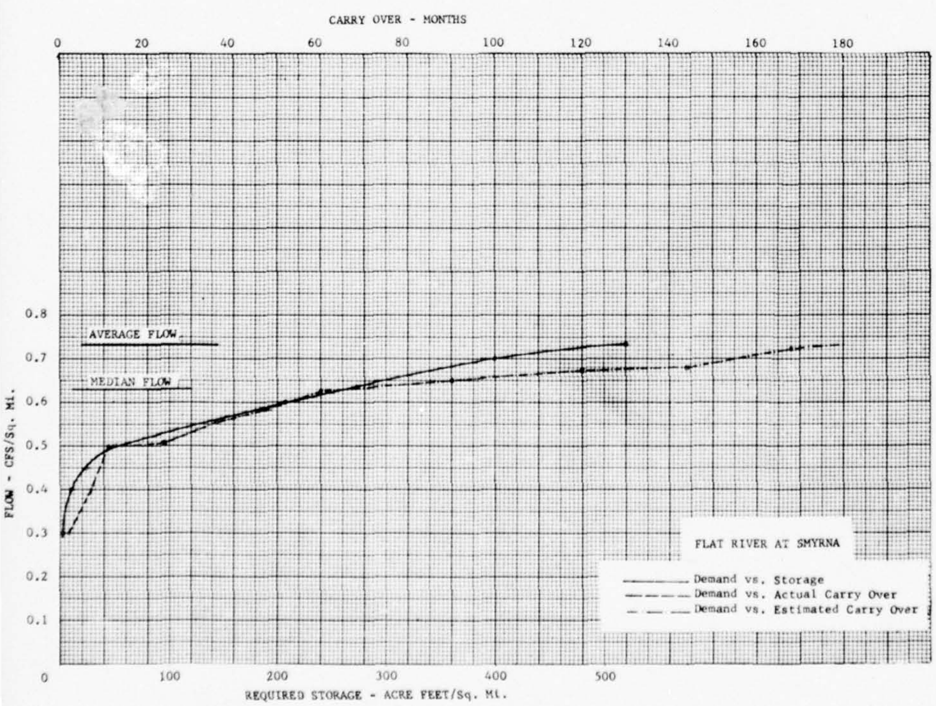




Storage - Yield Curve
FLAT RIVER AT SMYRNA



Optimum Flow - Storage Development
FLAT RIVER AT SMYRNA

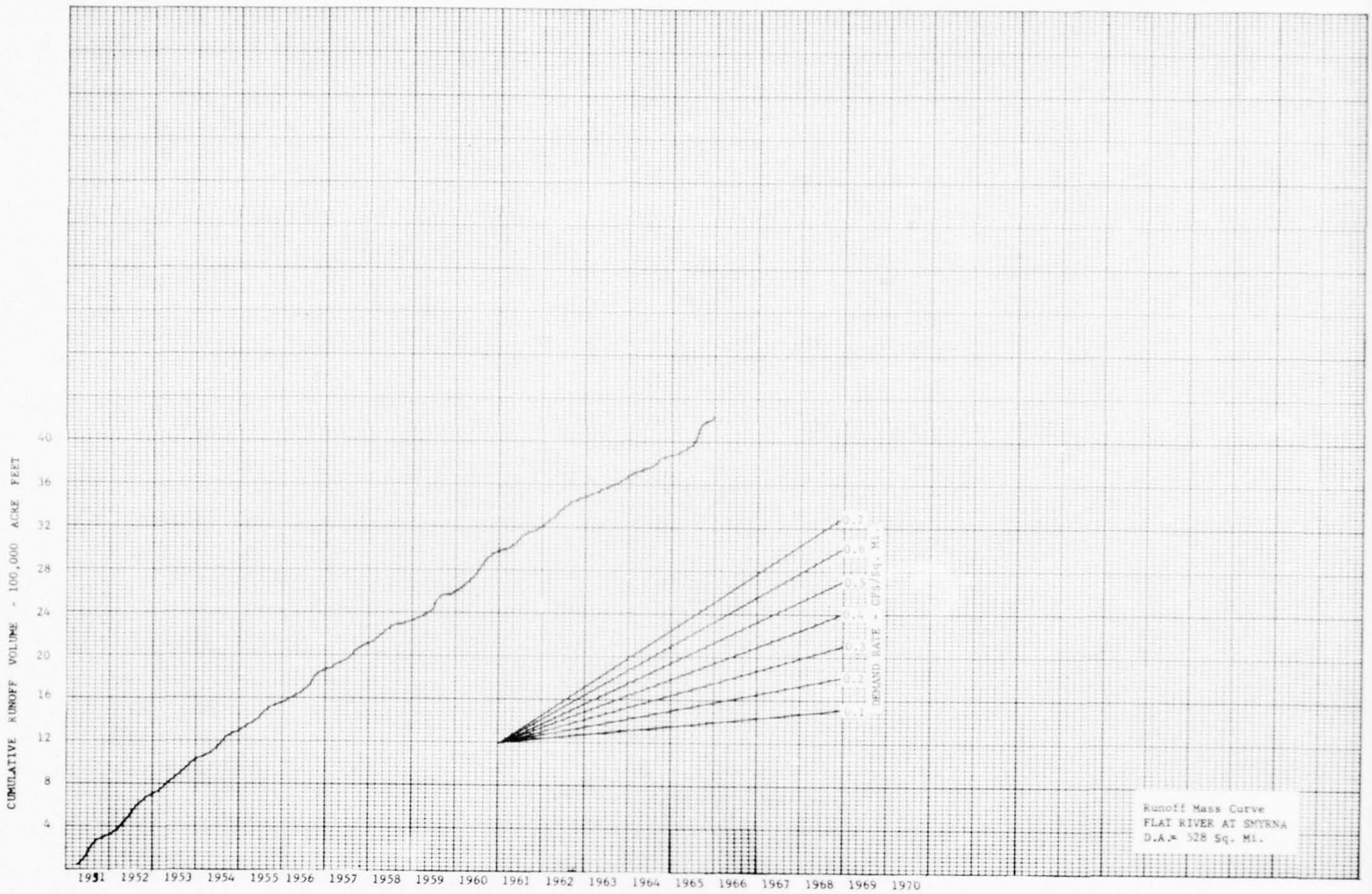


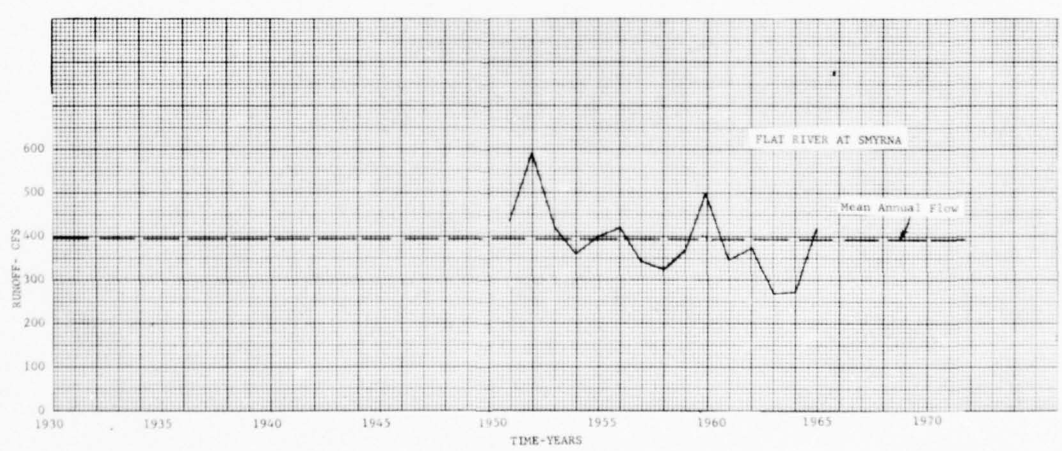
GRAND RIVER BASIN

QUANTITATIVE STUDY OF
STREAMFLOW DATA

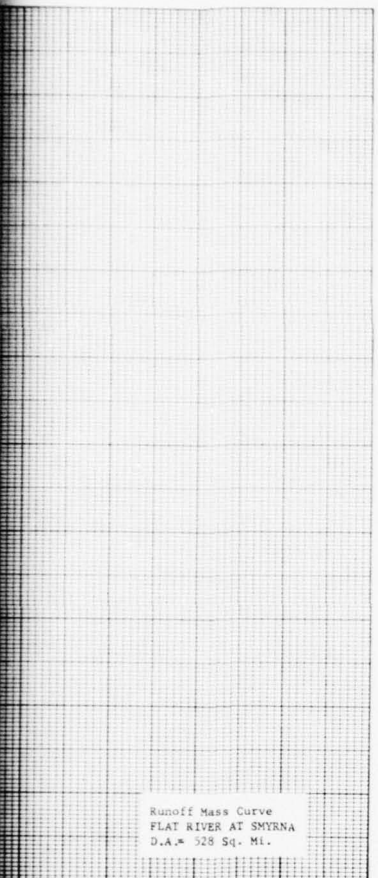
FLAT RIVER
AT SMYRNA

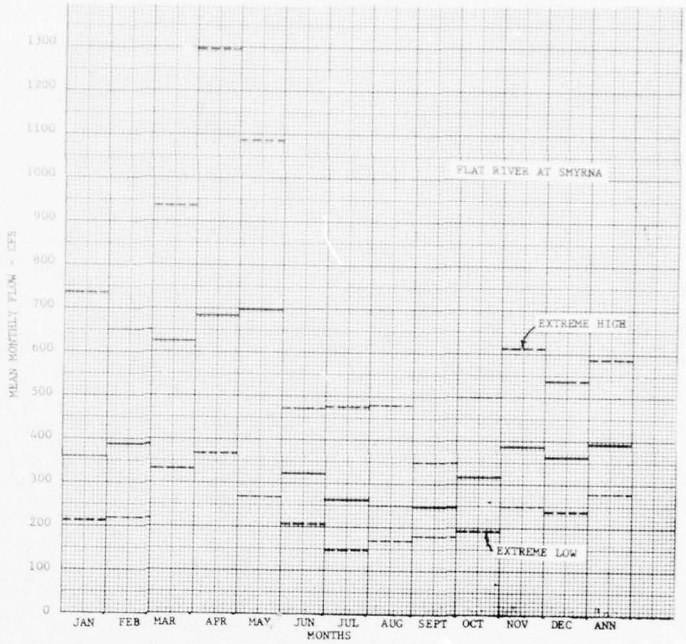
U.S. ARMY ENGINEER DISTRICT, DETROIT

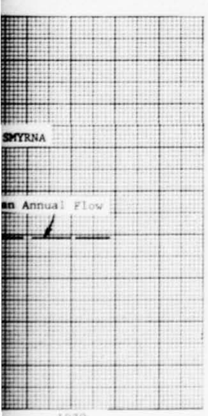

CUMULATIVE RUNOFF VOLUME - 100,000 ACRE FEET
DEMAND RATE - CFS/Sq. Mi.
Runoff Mass Curve
FLAT RIVER AT SMYRNA
D.A.= 528 Sq. Mi.


FLAT RIVER AT SMYRNA
Mean Annual Flow
RUNOFF- CFS
TIME-YEARS

U.S. ARMY







GRAND RIVER BASIN

QUANTITATIVE STUDY OF STREAMFLOW DATA

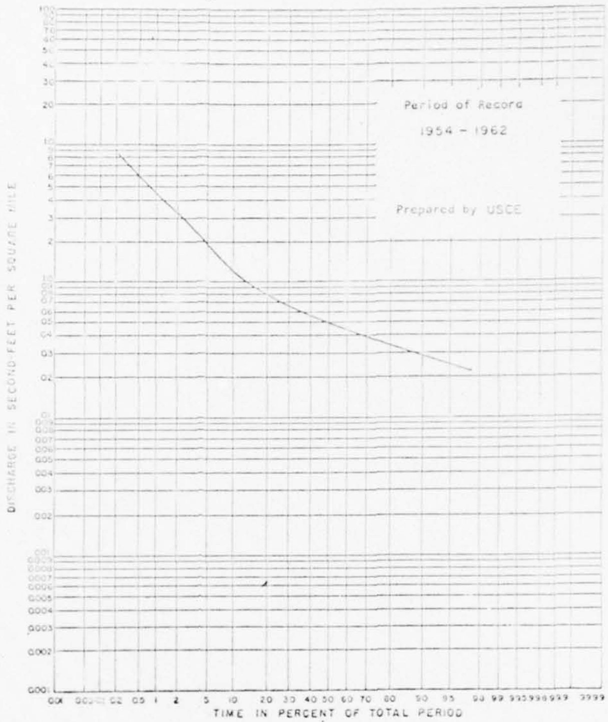
FLAT RIVER AT SMYRNA

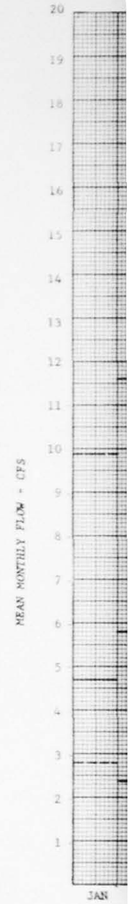
U.S. ARMY ENGINEER DISTRICT, DETROIT

FLOW DURATION CURVE

QUAKER BROOK AT NASHVILLE

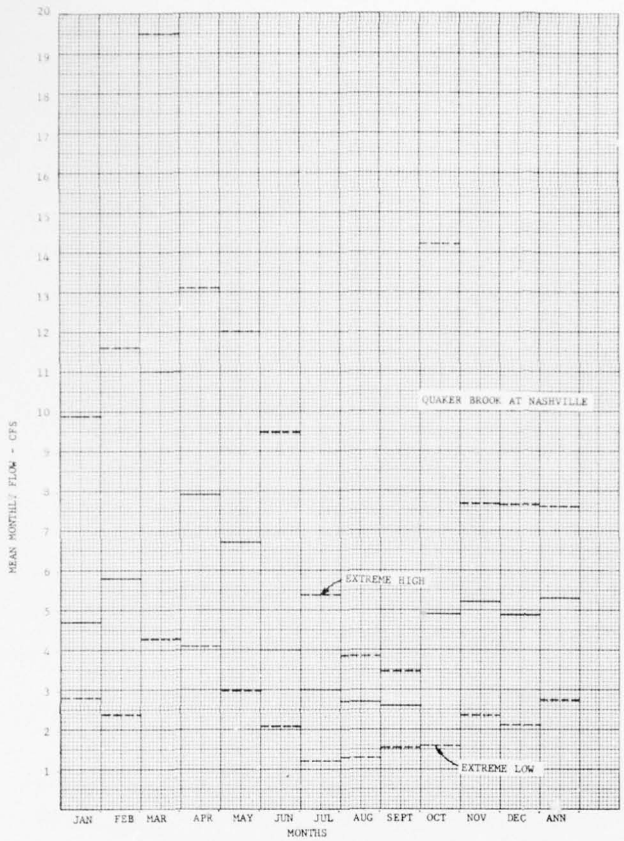
Drainage Area 7.6 square miles

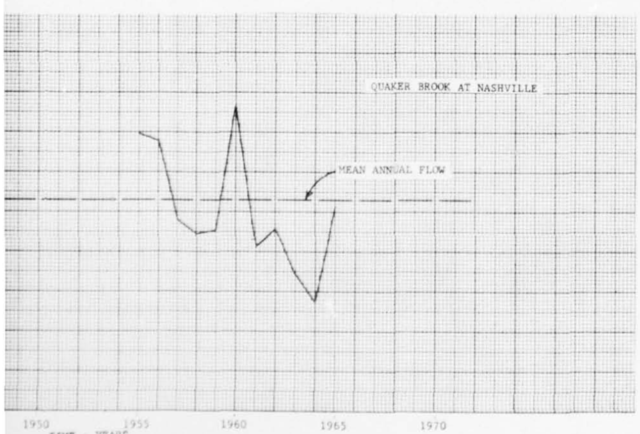




CORPS OF ENGINEERS

U.S. ARMY



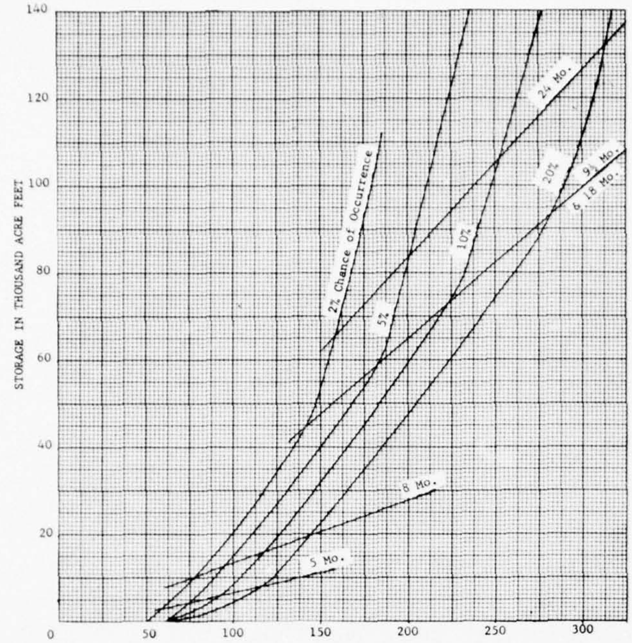


GRAND RIVER BASIN

QUANTITATIVE STUDY OF STREAMFLOW DATA

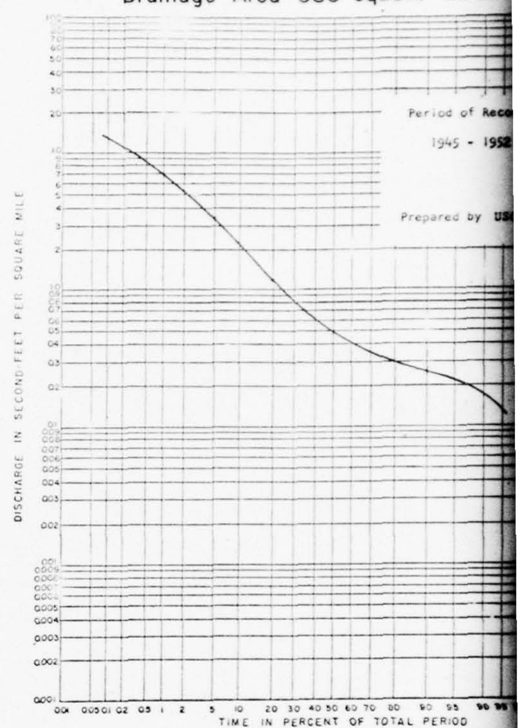
QUAKER BROOK AT NASHVILLE

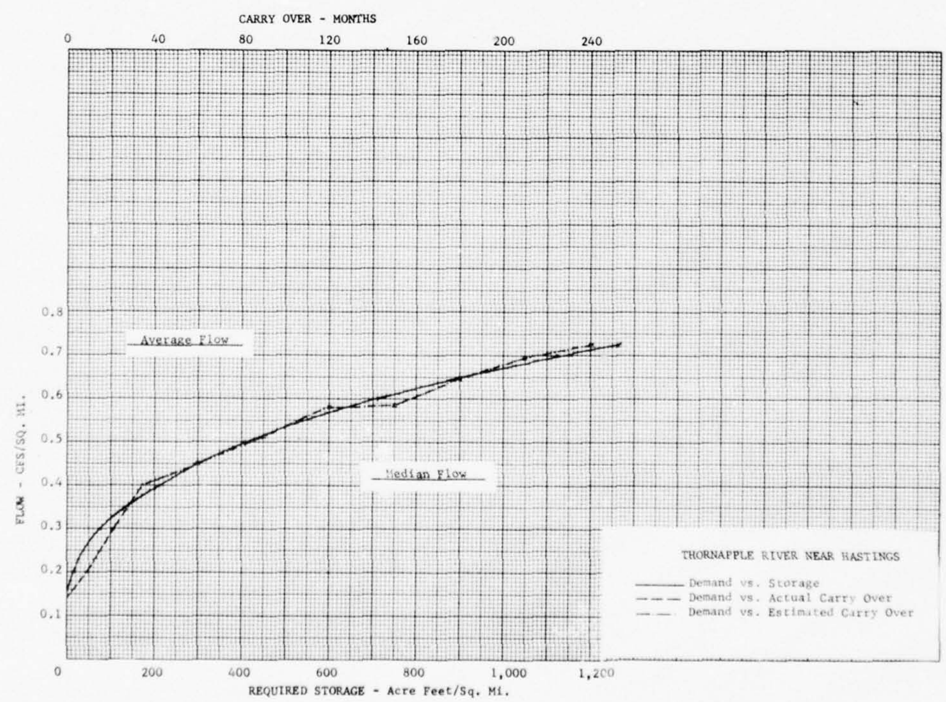
U.S. ARMY ENGINEER DISTRICT, DETROIT

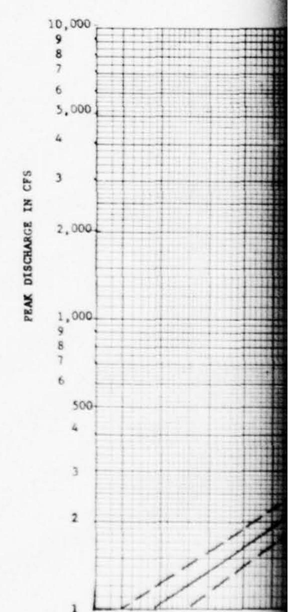


Yield in CFS
Storage - Yield Curve
THORNAPPLE RIVER NEAR HASTINGS

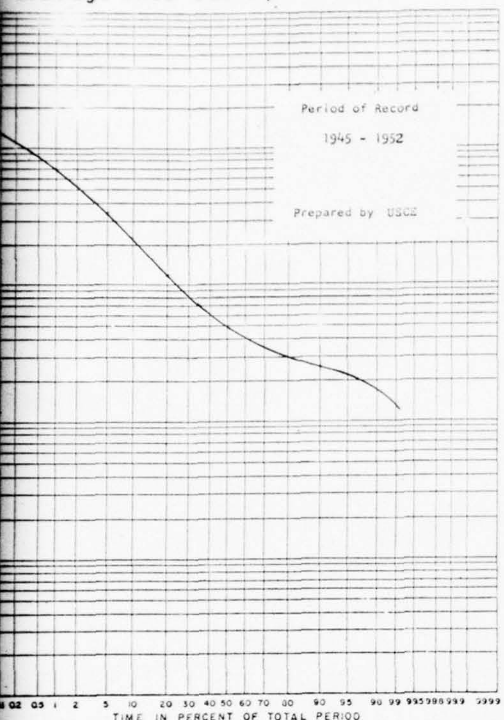
FLOW DURATION CURVE
THORNAPPLE RIVER AT HASTINGS
Drainage Area 385 square miles

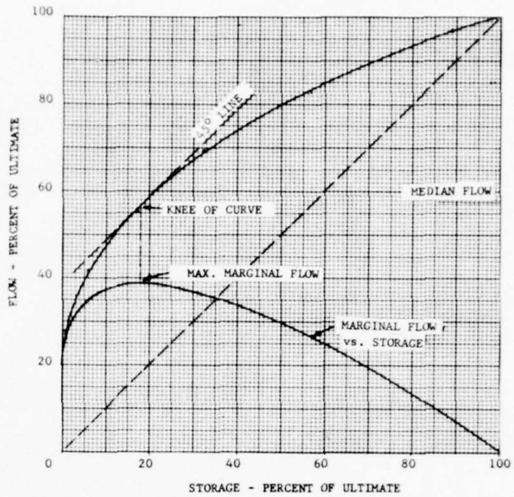




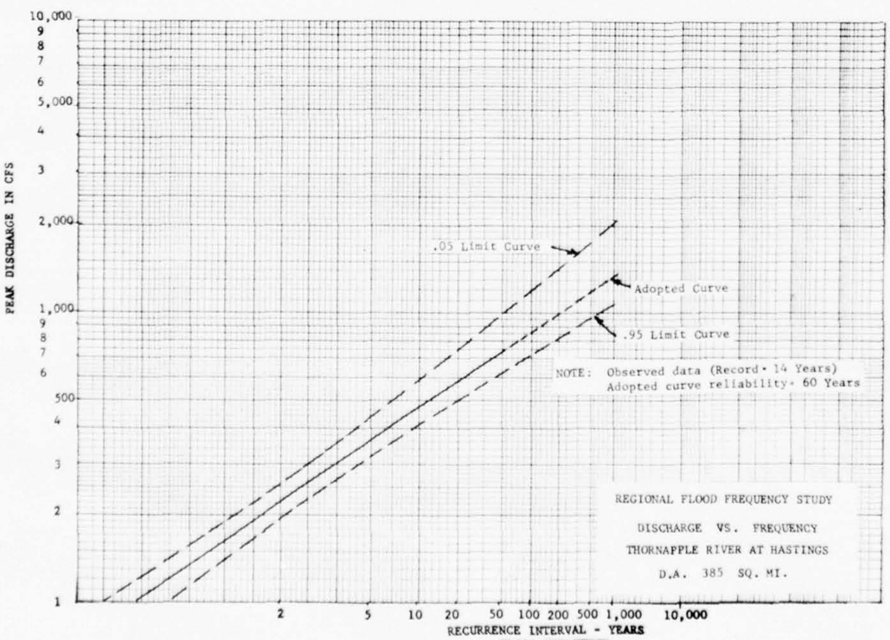


FLOW DURATION CURVE
THORNAPPLE RIVER AT HASTINGS
Drainage Area 385 square miles





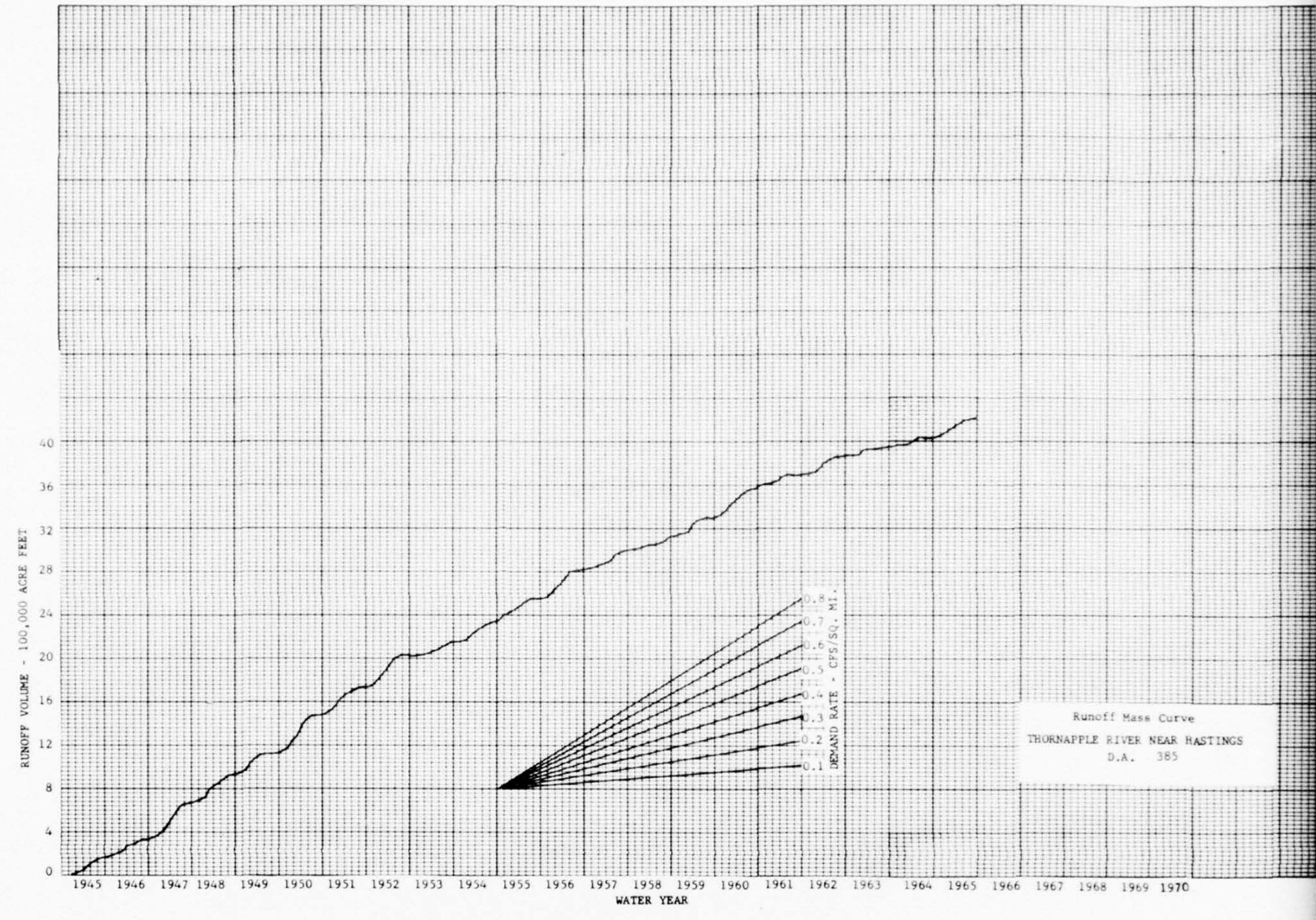
Optimum Flow - Storage Development
THORNAPPLE RIVER NEAR HASTINGS

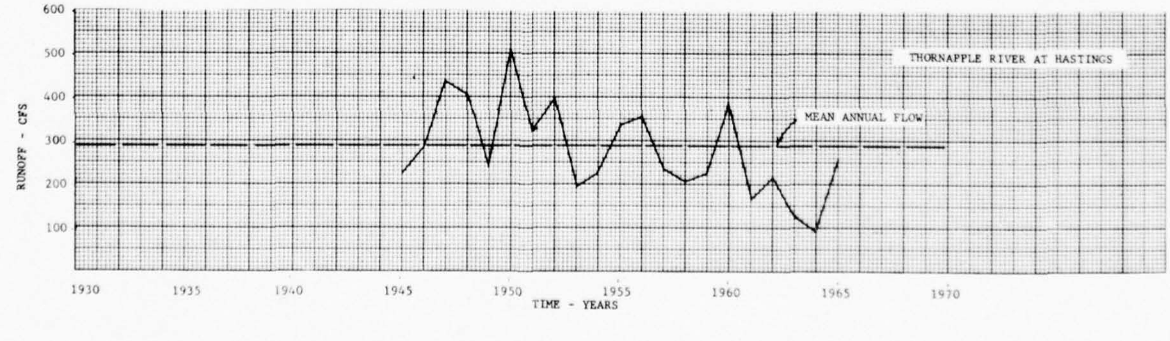


FLOOD FREQUENCY

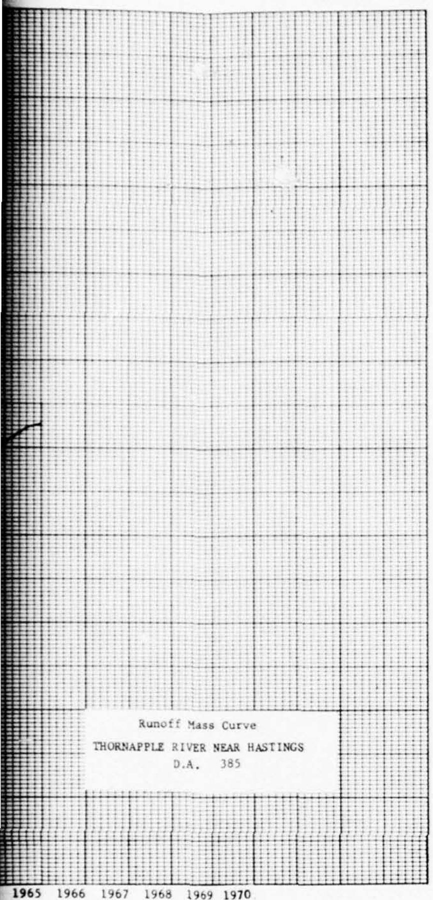
GRAND RIVER BASIN
QUANTITATIVE STUDY OF STREAMFLOW DATA
THORNAPPLE RIVER NEAR HASTINGS

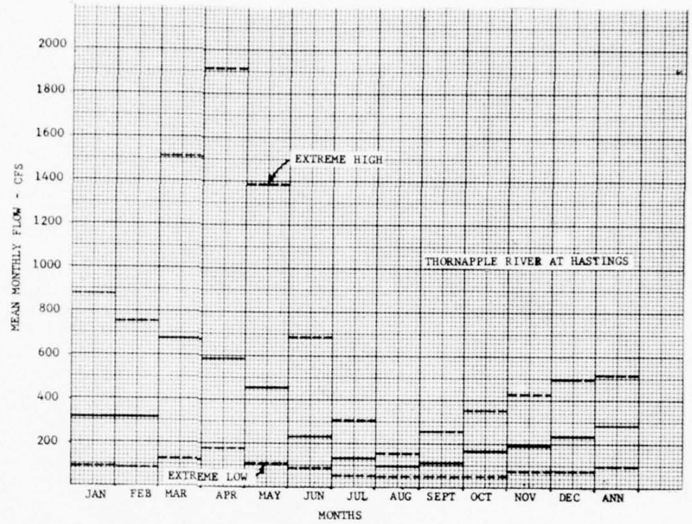
U.S. ARMY ENGINEER DISTRICT, DETROIT


Runoff Mass Curve
THORNAPPLE RIVER NEAR HASTINGS
D.A. 385
RUNOFF VOLUME - 100,000 ACRE FEET
DEMAND RATE - CFS/SQ. MI.
WATER YEAR


THORNAPPLE RIVER AT HASTINGS
MEAN ANNUAL FLOW
RUNOFF - CFS
TIME - YEARS

U.S. ARMY





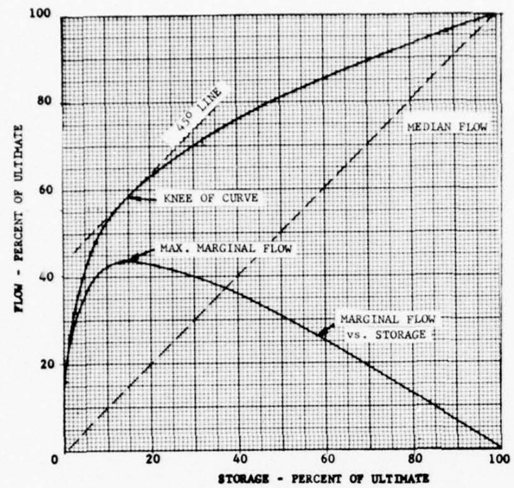
GRAND RIVER BASIN

QUANTITATIVE STUDY OF STREAMFLOW DATA

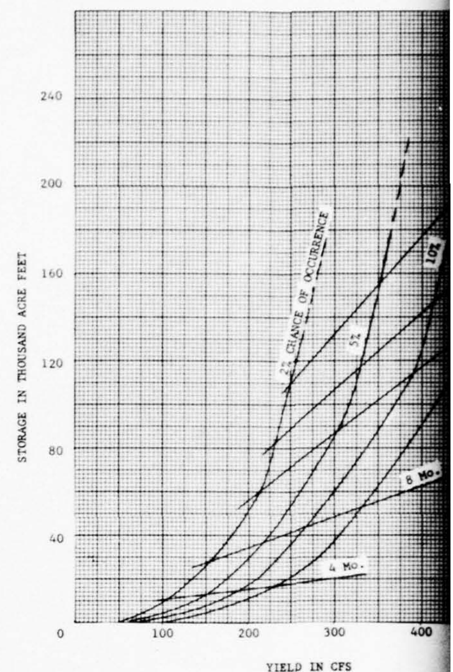
THORNAPPLE RIVER NEAR HASTINGS

U.S. ARMY ENGINEER DISTRICT, DETROIT

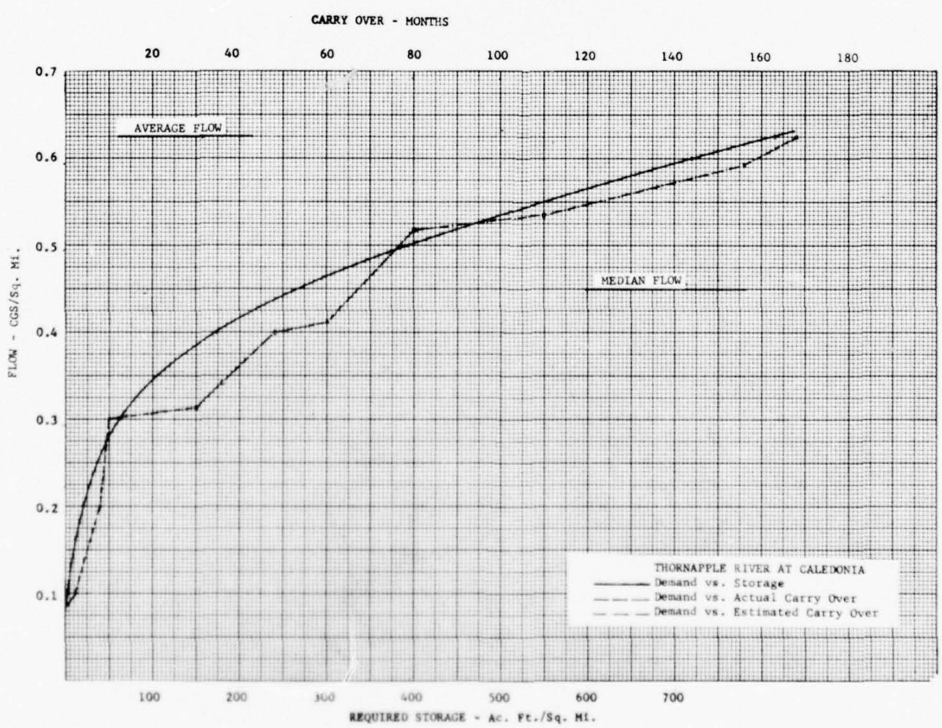
PLATE D-15B

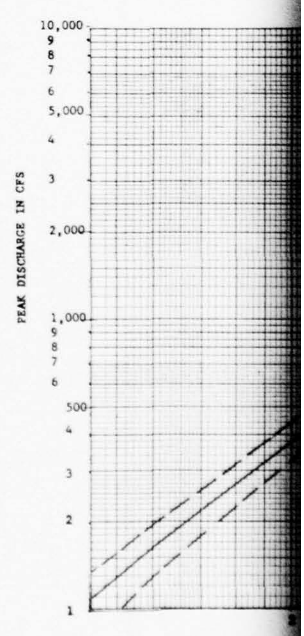


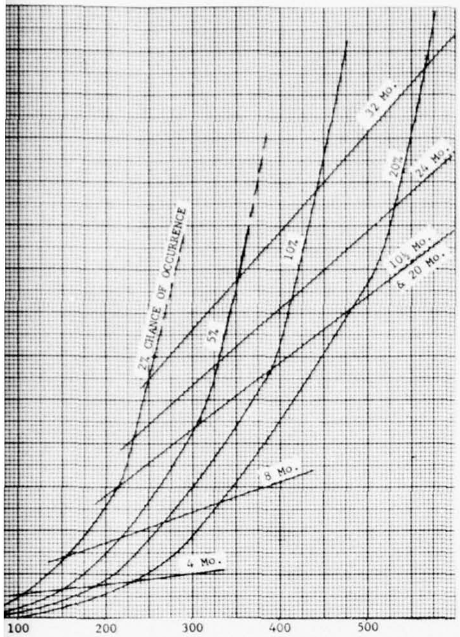
Optimum Flow - Storage Development
THORNAPPLE RIVER AT CALEDONIA
(1931-1938 & 1952-1965)



Storage - Yield Curve
THORNAPPLE RIVER AT CALEDONIA
(1952-1965)



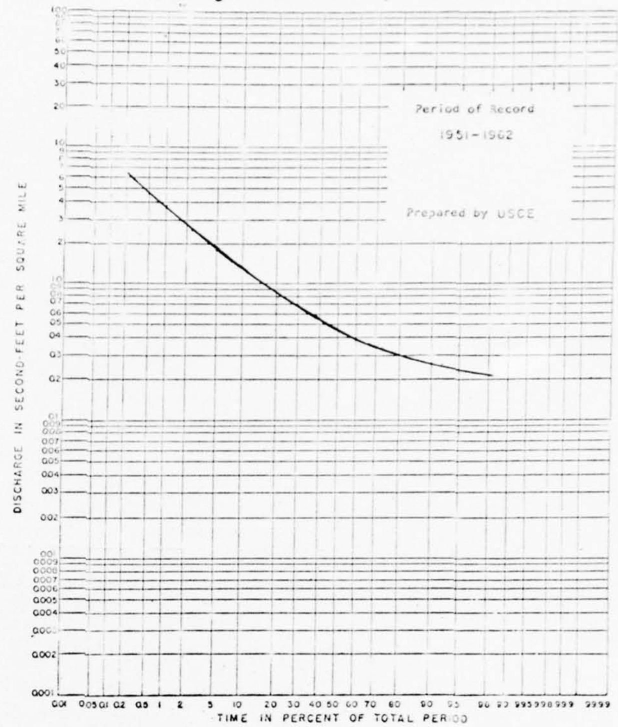


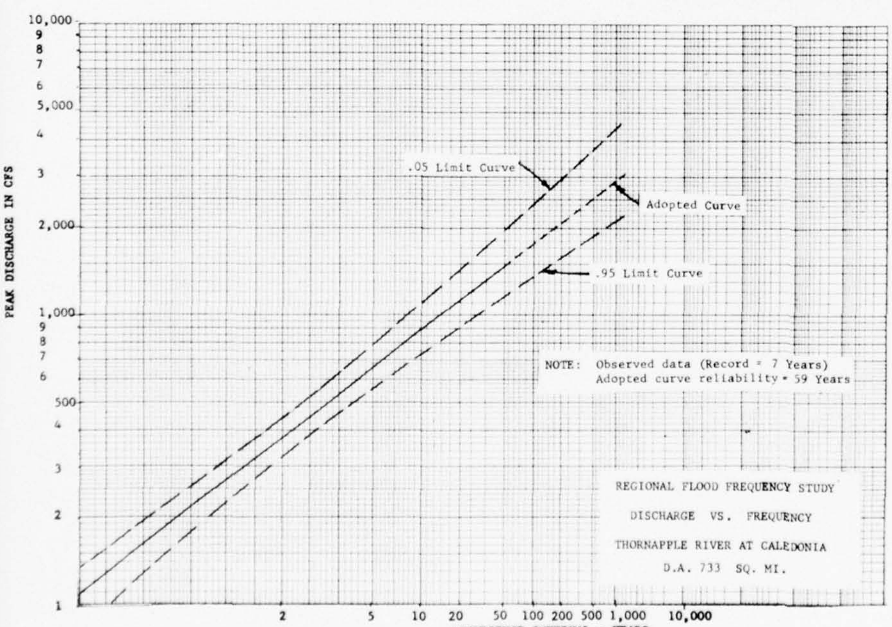


YIELD IN CFS

Storage - Yield Curve
THORNAPPLE RIVER AT CALEDONIA
(1952-1965)

FLOW DURATION CURVE
THORNAPPLE RIVER AT CALEDONIA
Drainage Area 773 square miles





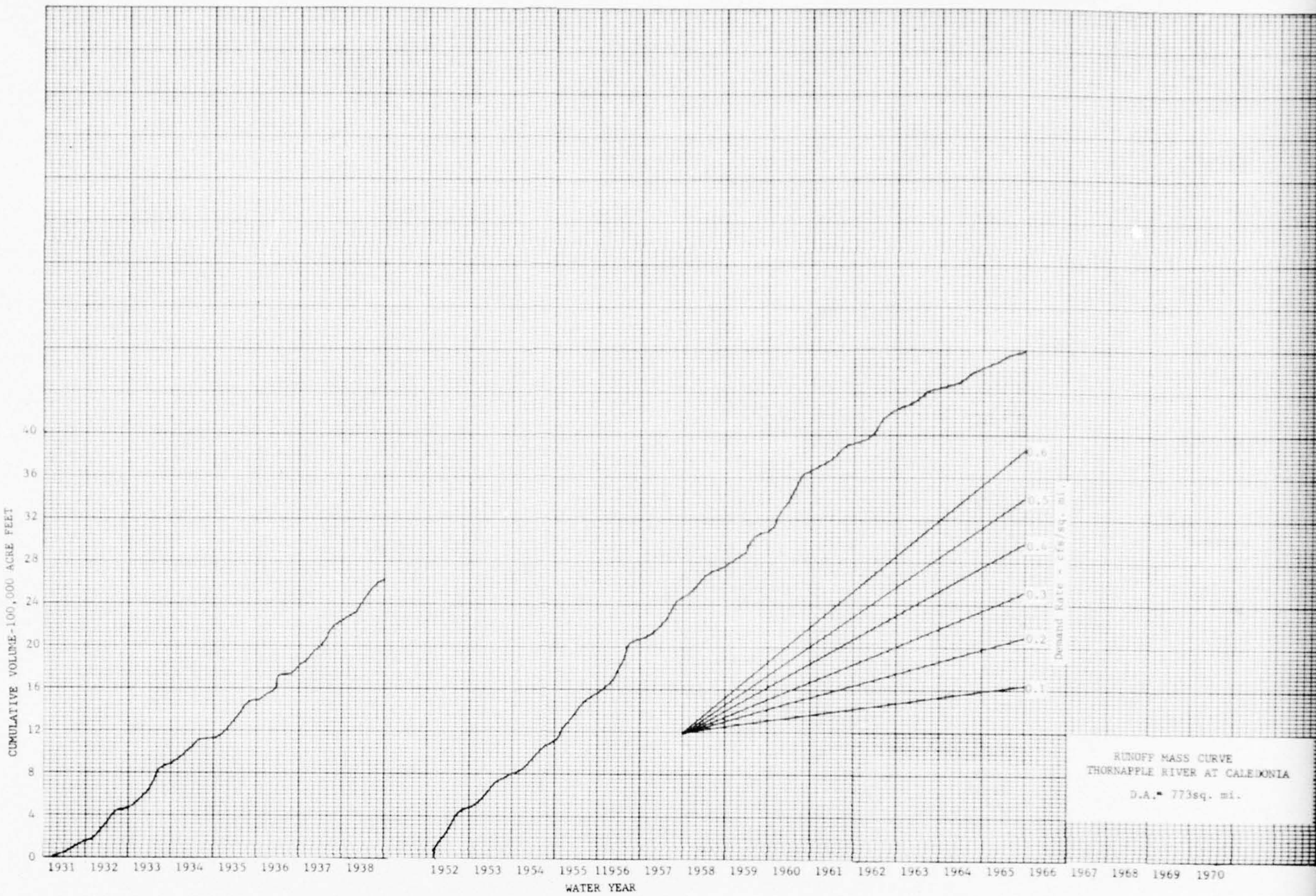
FLOOD FREQUENCY

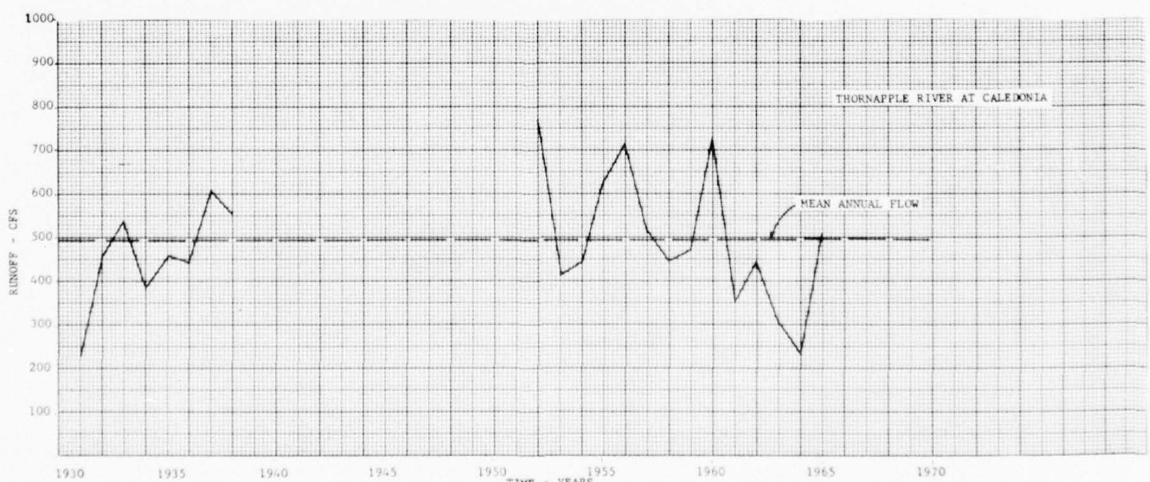
GRAND RIVER BASIN

QUANTITATIVE STUDY OF STREAMFLOW DATA

THORNAPPLE RIVER AT CALEDONIA

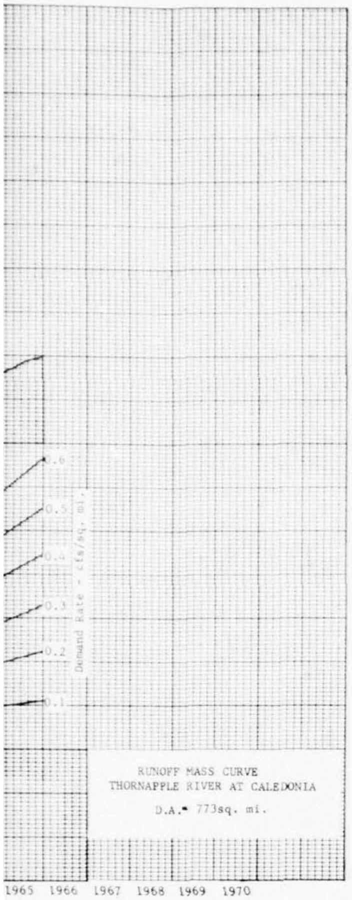
U.S. ARMY ENGINEER DISTRICT, DETROIT

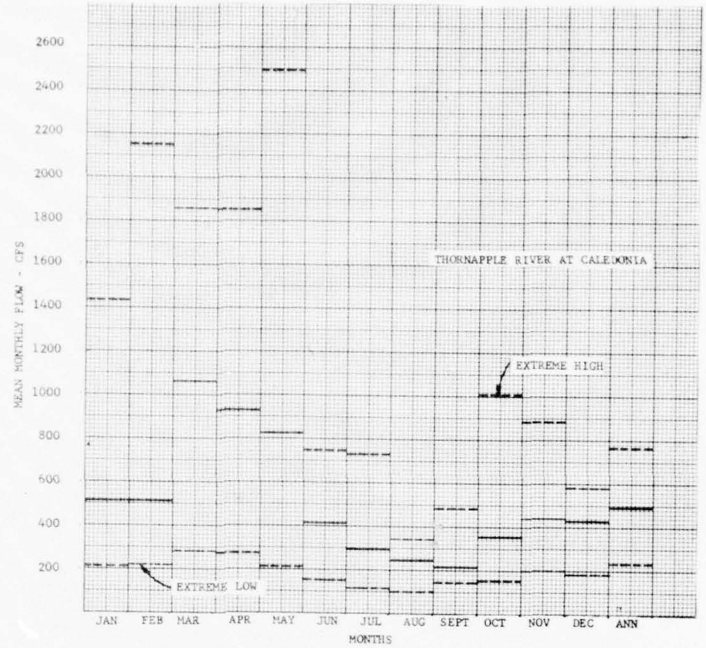

RUNOFF MASS CURVE
THORNAPPLE RIVER AT CALEDONIA
D.A.= 773sq. mi.
CUMULATIVE VOLUME-100,000 ACRE FEET
WATER YEAR
Demand Rate - cfs/sq. mi.
0.6
0.5
0.4
0.3
0.2
0.1
0
4
8
12
16
20
24
28
32
36
40
1931
1932
1933
1934
1935
1936
1937
1938
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970

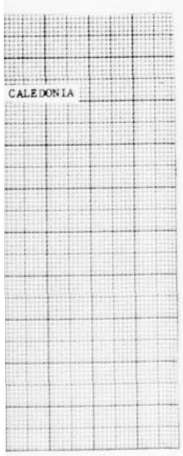

THORNAPPLE RIVER AT CALEDONIA
MEAN ANNUAL FLOW
RUNOFF - CFS
TIME - YEARS
1000
900
800
700
600
500
400
300
200
100
1930
1935
1940
1945
1950
1955
1960
1965
1970

U.S. ARMY

2







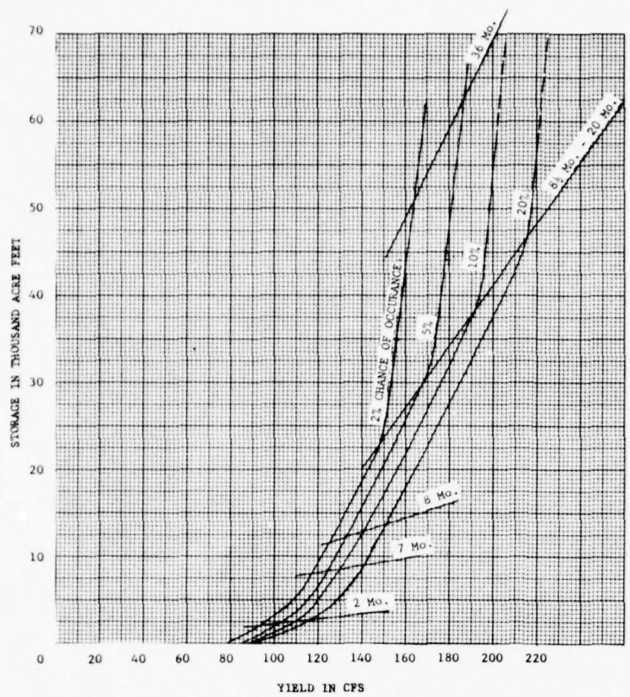
GRAND RIVER BASIN

QUANTITATIVE STUDY OF STREAMFLOW DATA

THORNAPPLE RIVER AT CALEDONIA

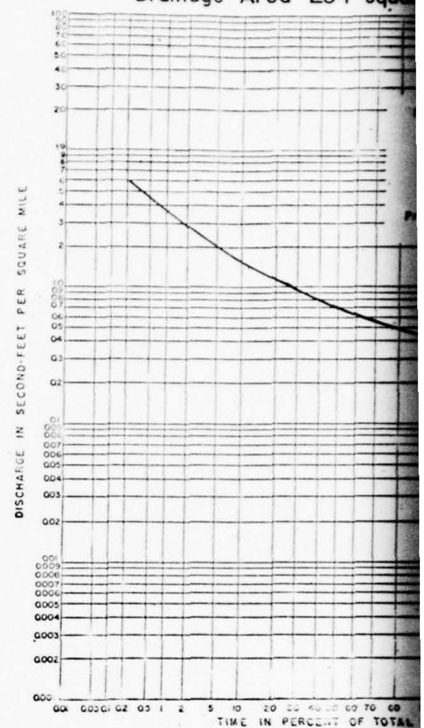
U.S. ARMY ENGINEER DISTRICT, DETROIT

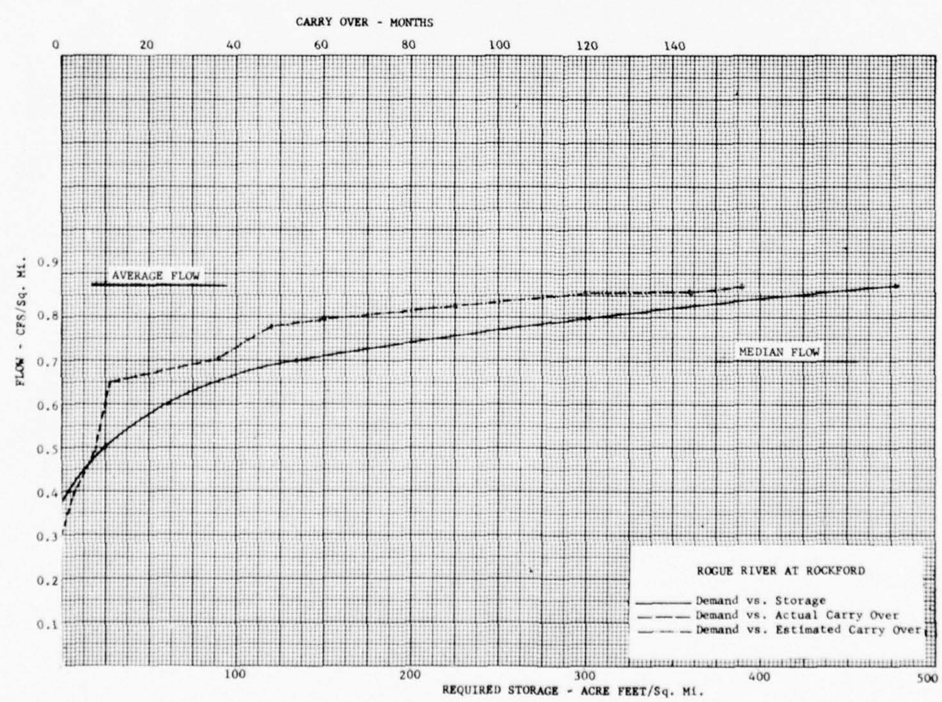
PLATE D-16B

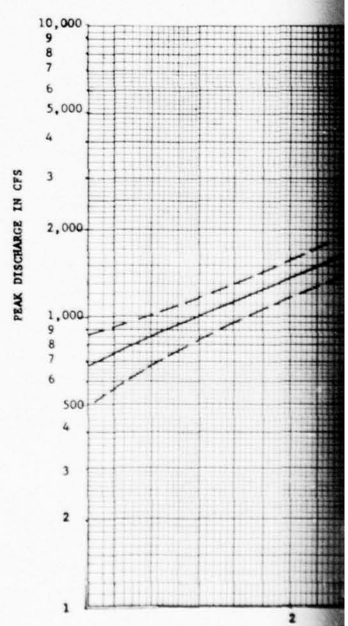


Storage - Yield Curve
ROGUE RIVER AT ROCKFORD

FLOW DURATION
ROGUE RIVER AT ROC
Drainage Area 234 squa



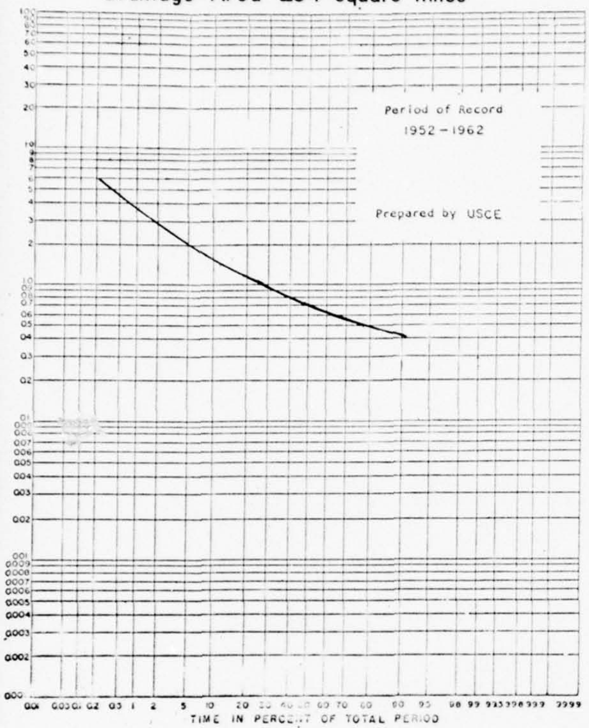


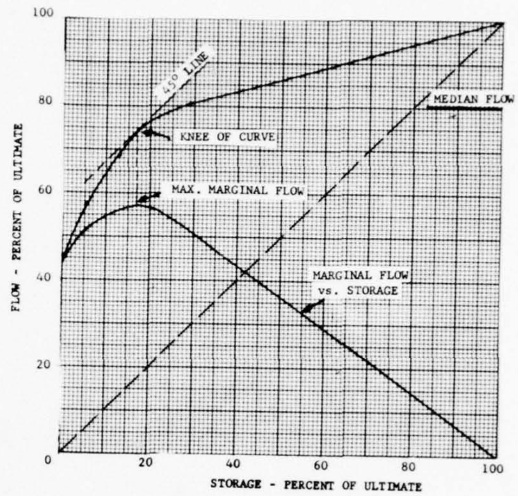


FLOW DURATION CURVE

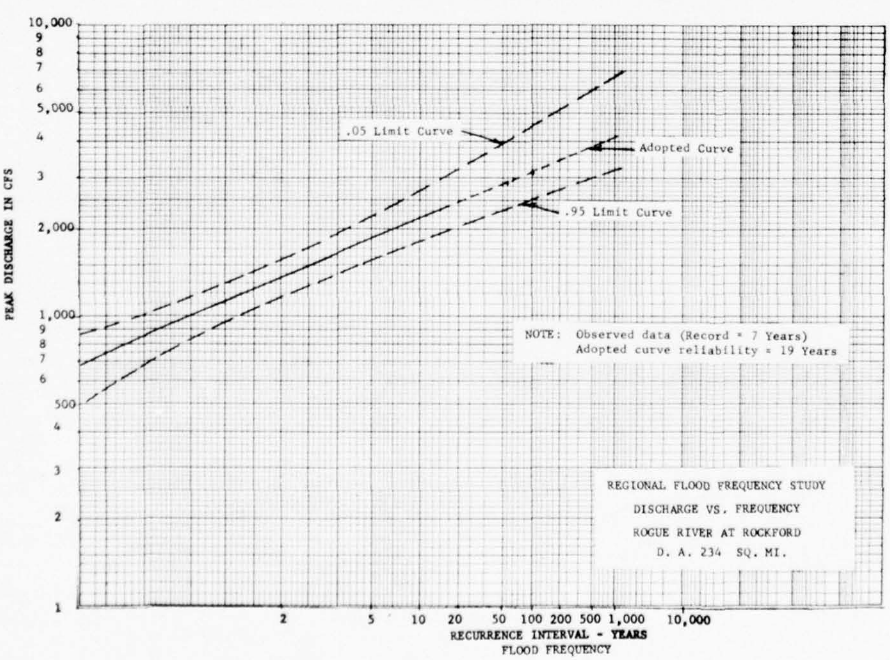
ROGUE RIVER AT ROCKFORD

Drainage Area 234 square miles





Optimum Flow - Storage Development
ROGUE RIVER AT ROCKFORD

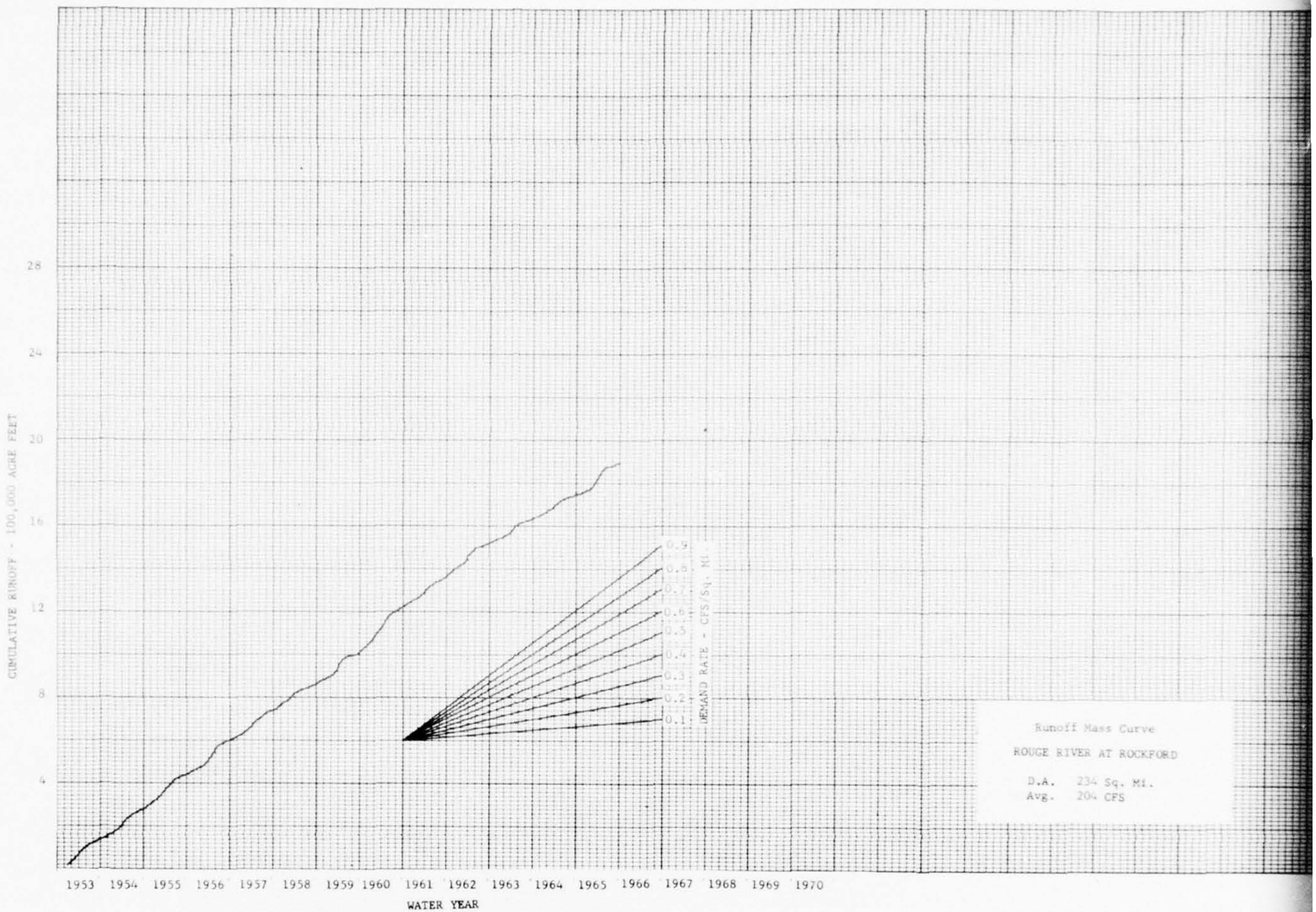


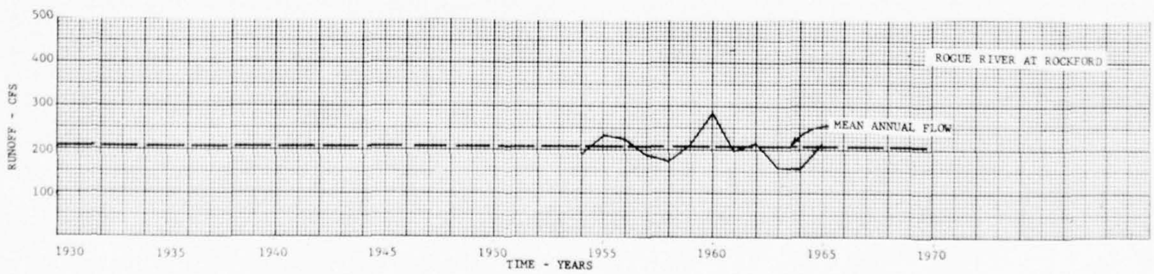
GRAND RIVER BASIN

QUANTITATIVE STUDY OF STREAMFLOW DATA

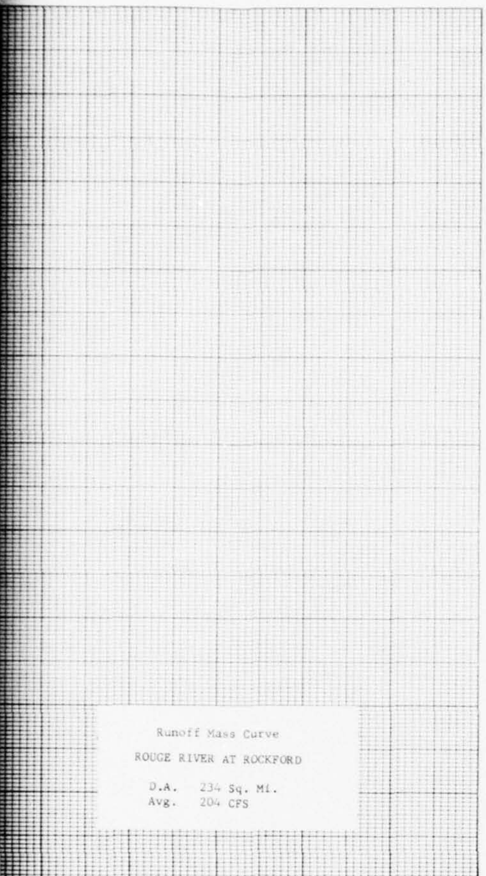
ROGUE RIVER AT ROCKFORD

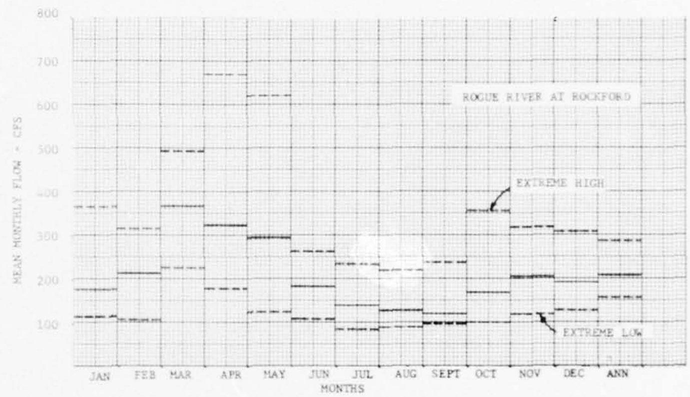
U.S. ARMY ENGINEER DISTRICT, DETROIT

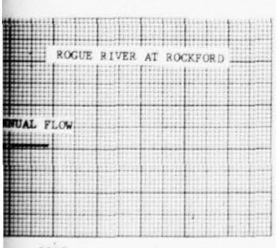

CUMULATIVE RUNOFF - 100,000 ACRE FEET
28
24
20
16
12
8
4
1953
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
WATER YEAR
DEMAND RATE - CFS/Sq. Mi.
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Runoff Mass Curve
ROUGE RIVER AT ROCKFORD
D.A. 234 Sq. Mi.
Avg. 204 CFS


RUNOFF - CFS
500
400
300
200
100
1930
1935
1940
1945
1950
1955
1960
1965
1970
TIME - YEARS
ROGUE RIVER AT ROCKFORD
MEAN ANNUAL FLOW

2







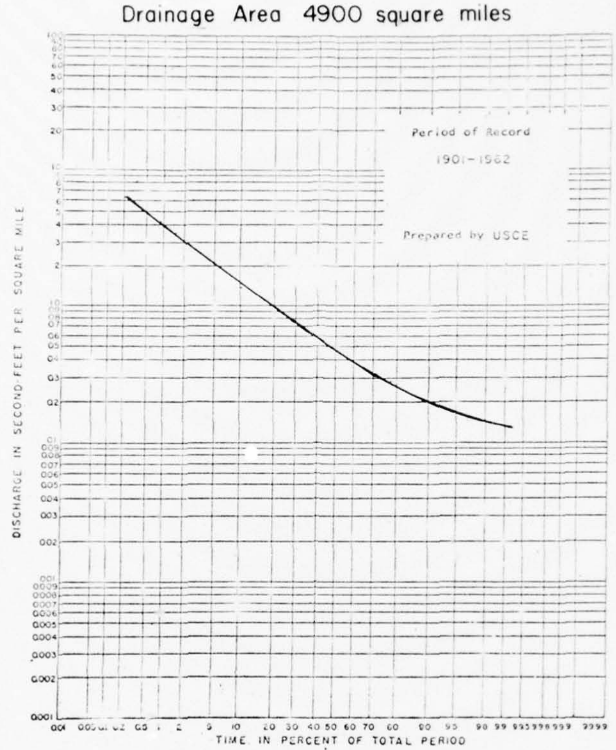
GRAND RIVER BASIN

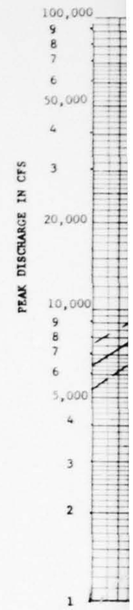
QUANTITATIVE STUDY OF STREAMFLOW DATA

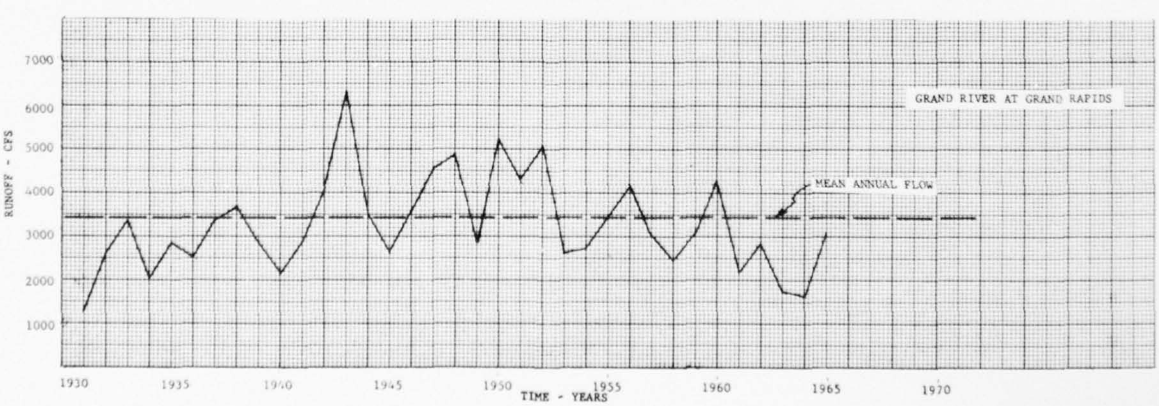
ROGUE RIVER AT ROCKFORD

U.S. ARMY ENGINEER DISTRICT, DETROIT

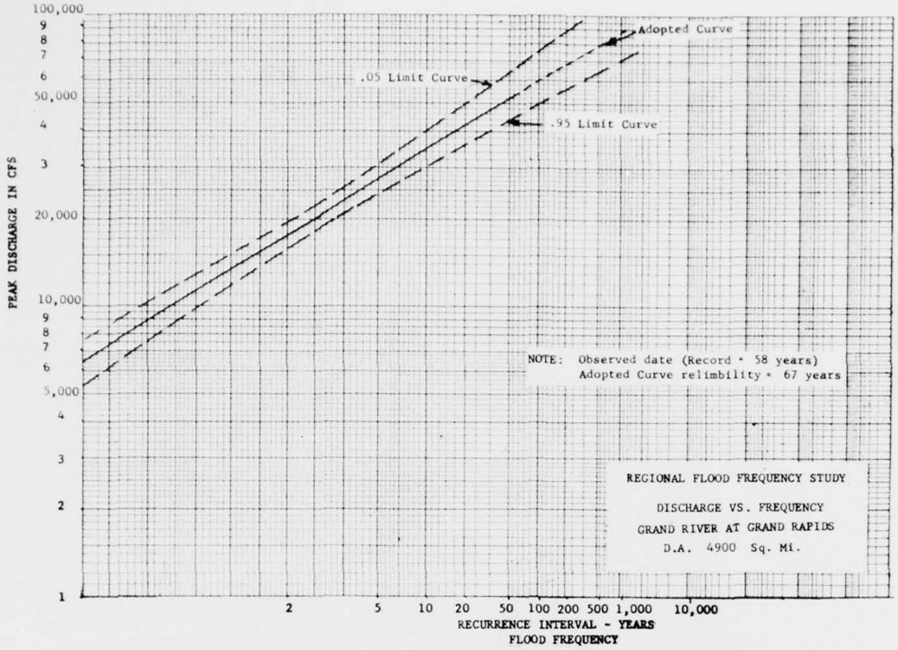
FLOW DURATION CURVE
GRAND RIVER AT GRAND RAPIDS
Drainage Area 4900 square miles

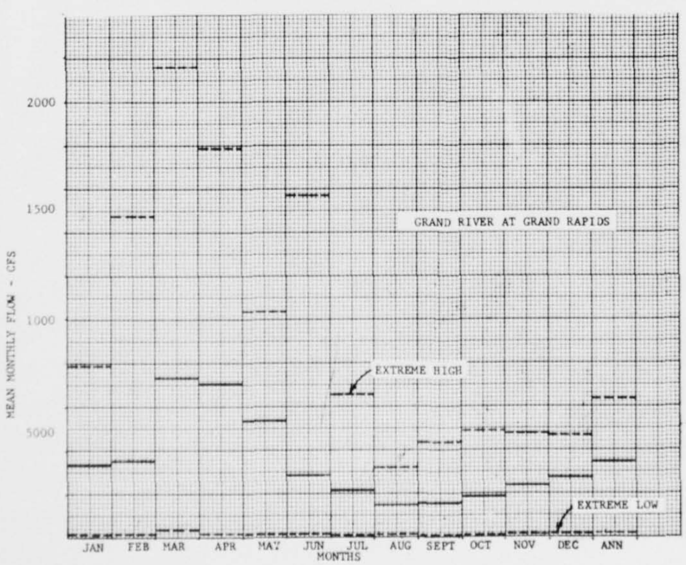






2



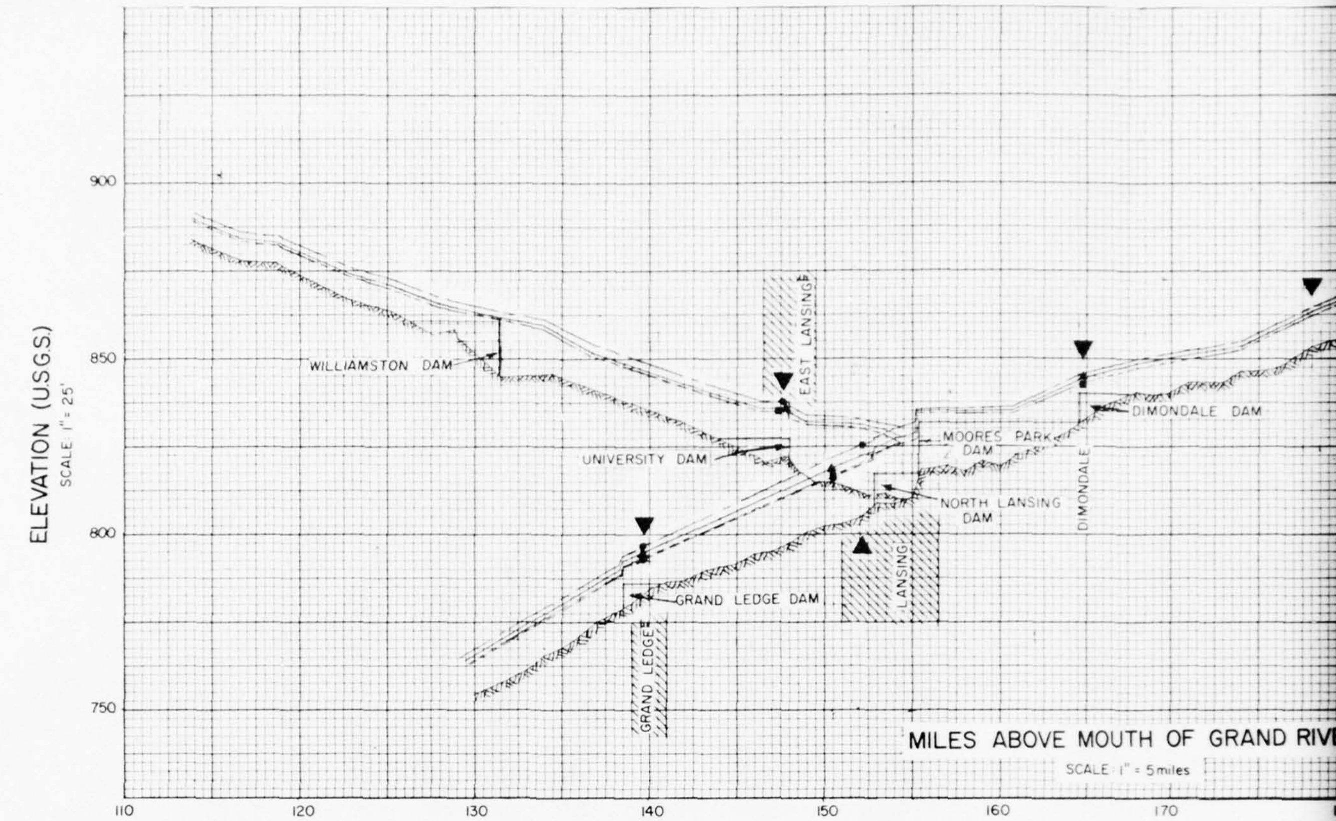


GRAND RIVER BASIN

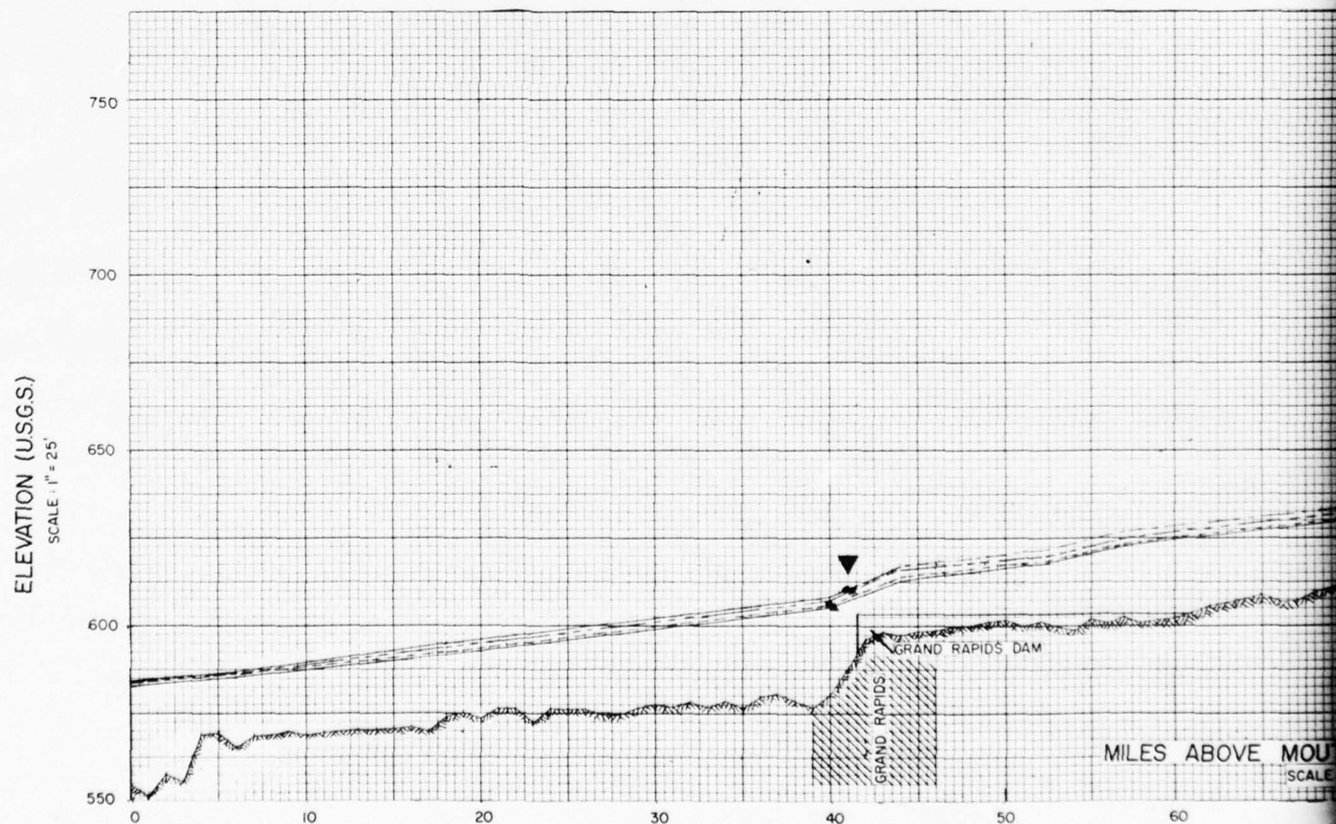
QUANTITATIVE STUDY OF STREAMFLOW DATA

GRAND RIVER AT GRAND RAPIDS

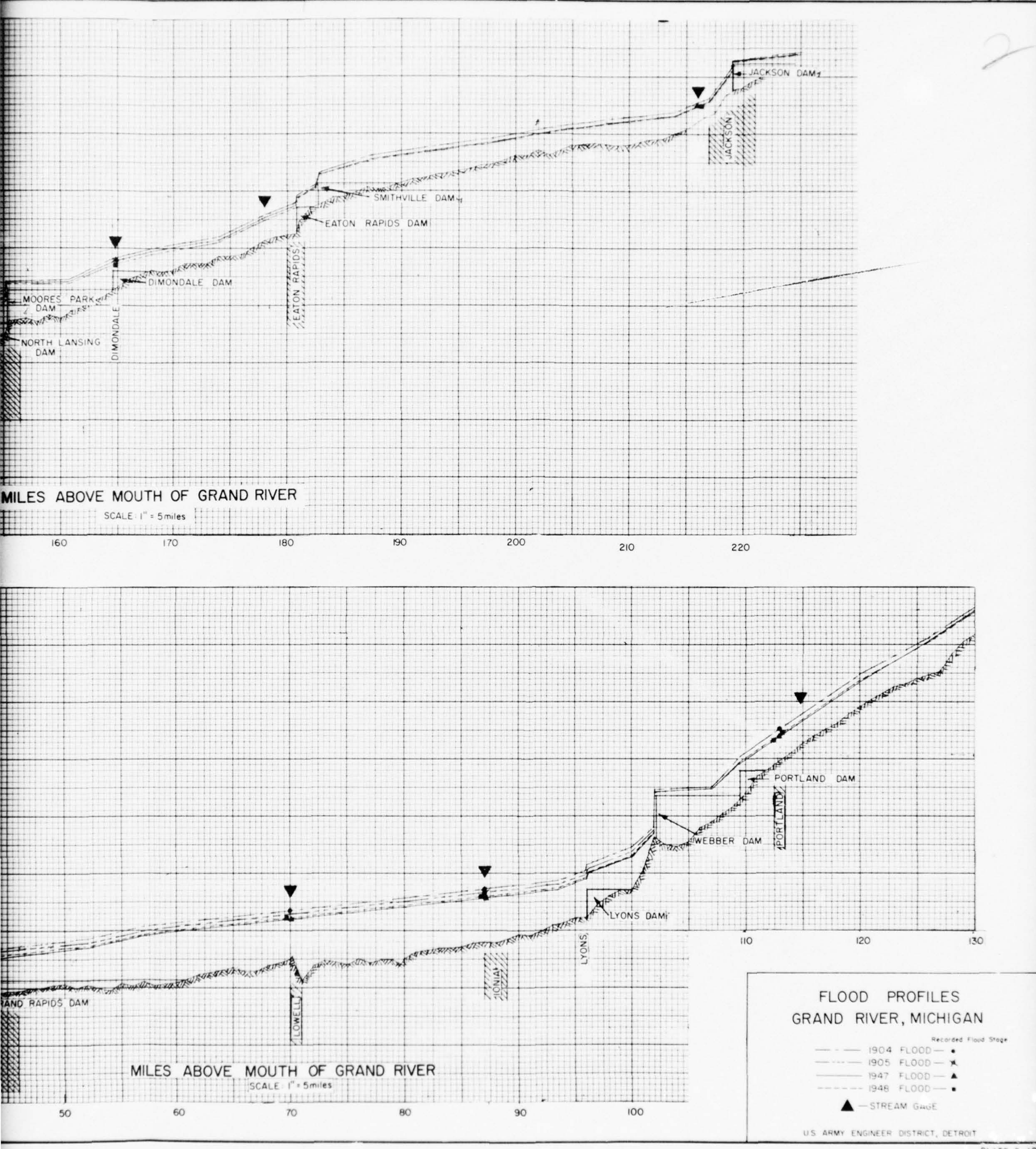
U.S. ARMY ENGINEER DISTRICT, DETROIT

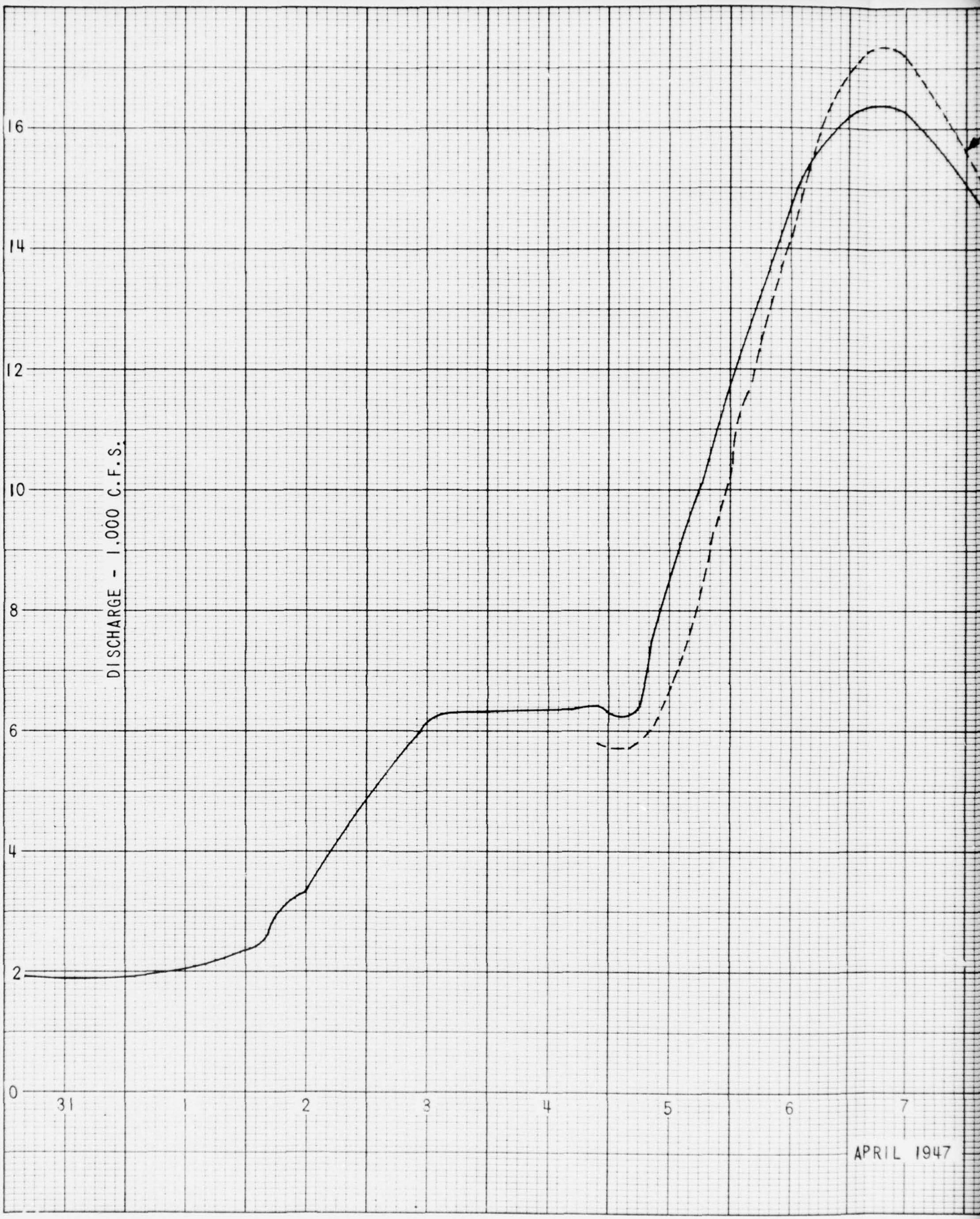


ELEVATION (U.S.G.S.)
SCALE 1" = 25'
900
850
800
750
WILLIAMSTON DAM
EAST LANSING
UNIVERSITY DAM
MOORES PARK DAM
NORTH LANSING DAM
DIMONDALE
DIMONDALE DAM
GRAND LEDGE DAM
GRAND LEDGE
LANSING
MILES ABOVE MOUTH OF GRAND RIVE
SCALE 1" = 5 miles
110
120
130
140
150
160
170

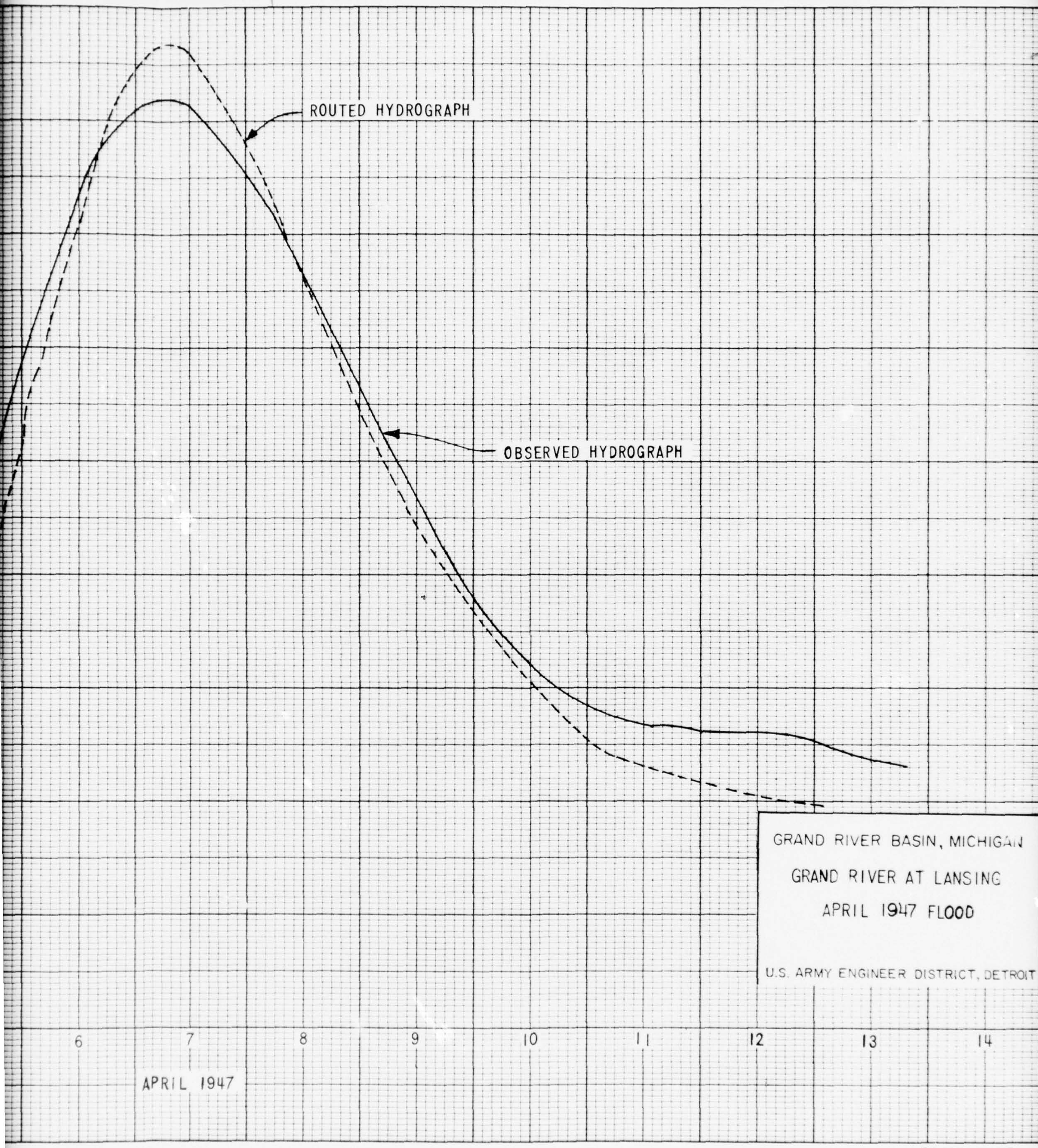


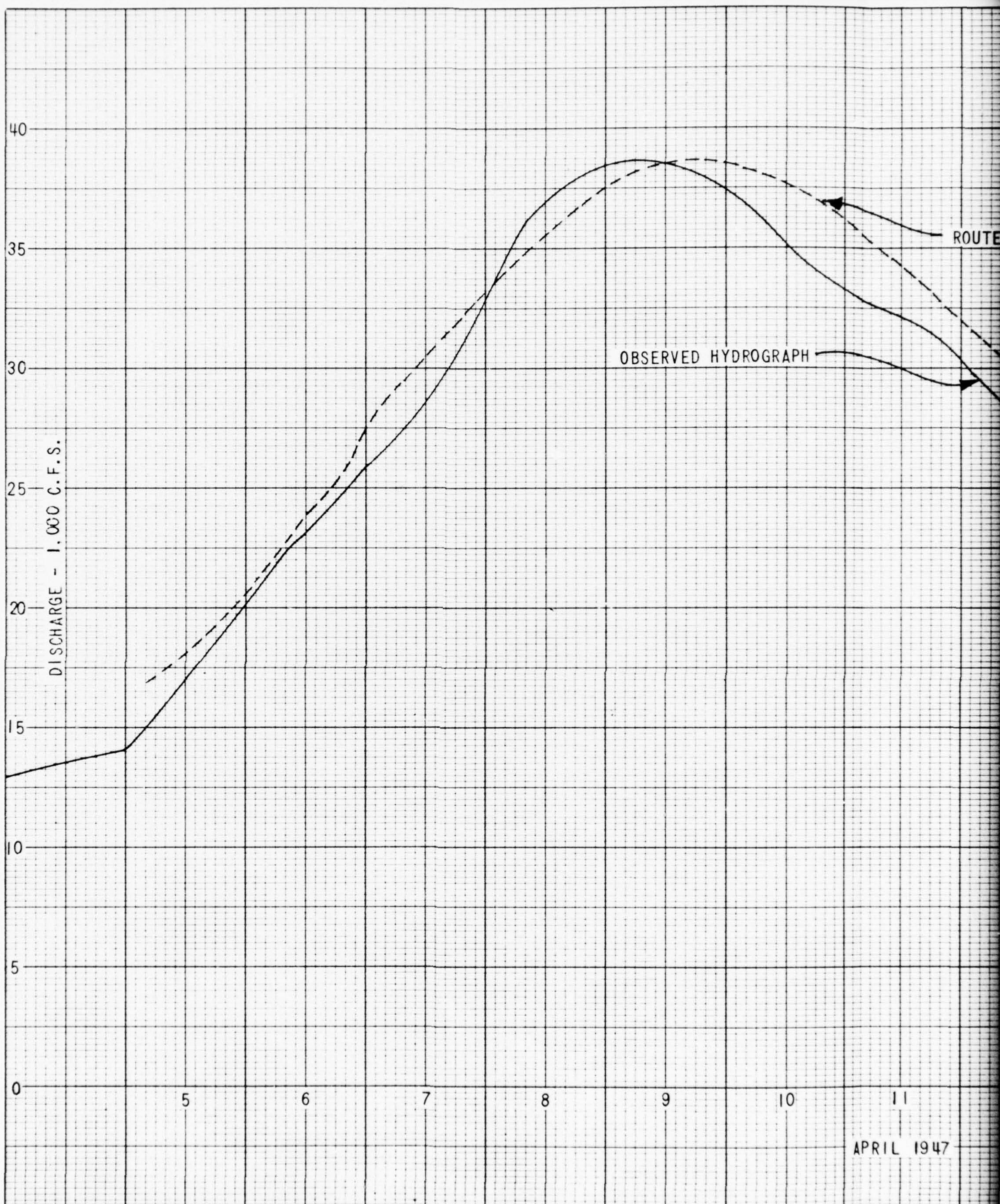
ELEVATION (U.S.G.S.)
SCALE 1" = 25'
750
700
650
600
550
GRAND RAPIDS DAM
GRAND RAPIDS
MILES ABOVE MOU
SCALE
0
10
20
30
40
50
60


JACKSON DAM
JACKSON
SMITHVILLE DAM
EATON RAPIDS DAM
EATON RAPIDS
DIMONDALE DAM
MOORES PARK DAM
DIMONDALE
NORTH LANSING DAM
MILES ABOVE MOUTH OF GRAND RIVER
SCALE: 1" = 5 miles
160
170
180
190
200
210
220
PORTLAND DAM
PORTLAND
WEBBER DAM
LYONS DAM
LYONS
IONIA
LOWELL
RAND RAPIDS DAM
MILES ABOVE MOUTH OF GRAND RIVER
SCALE: 1" = 5 miles
50
60
70
80
90
100
110
120
130
FLOOD PROFILES
GRAND RIVER, MICHIGAN
Recorded Flood Stage
1904 FLOOD
1905 FLOOD
1947 FLOOD
1948 FLOOD
STREAM GAGE
U.S. ARMY ENGINEER DISTRICT, DETROIT

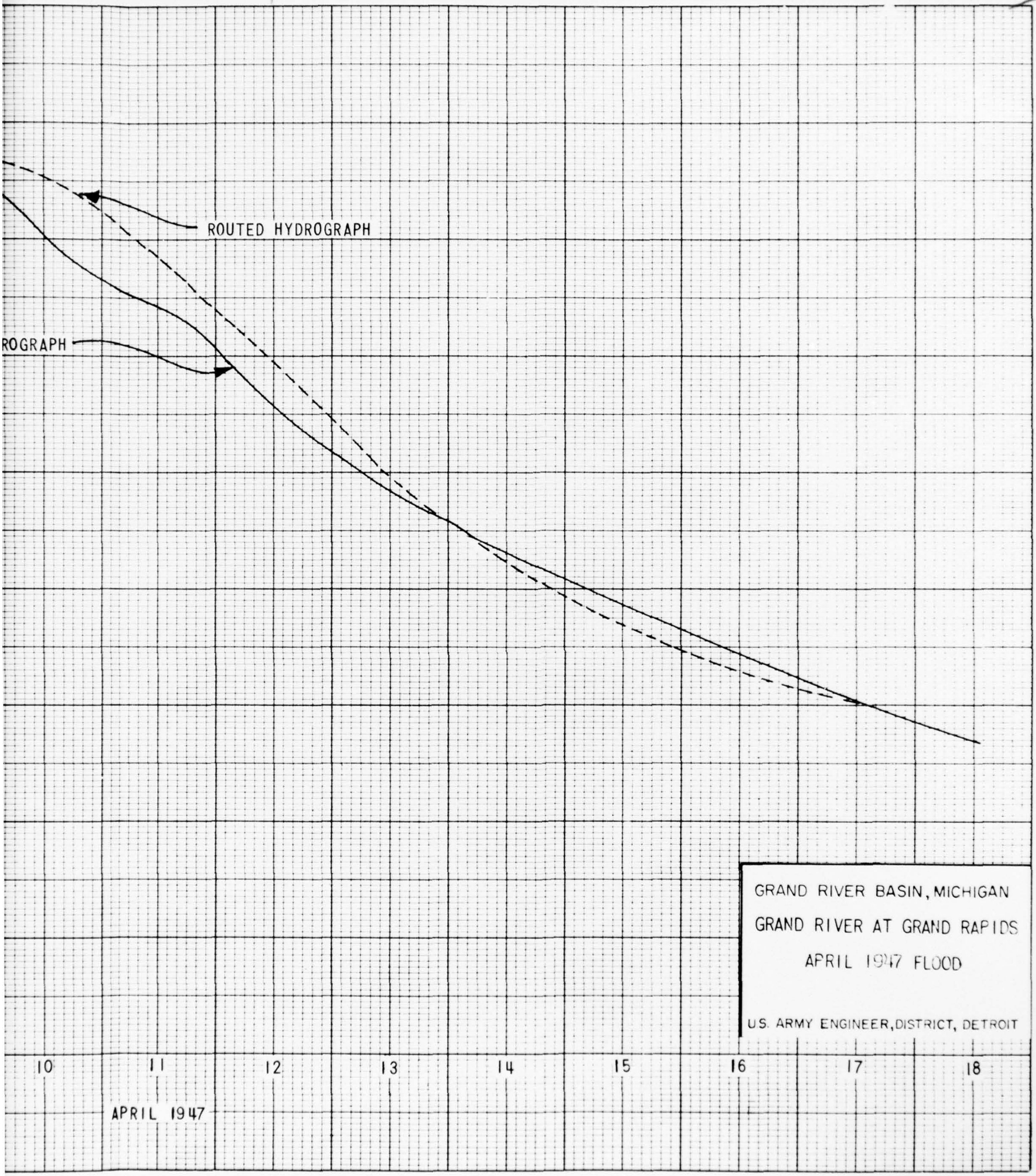


DISCHARGE - 1,000 C.F.S.
16
14
12
10
8
6
4
2
0
31
1
2
3
4
5
6
7
APRIL 1947


ROUTED HYDROGRAPH
OBSERVED HYDROGRAPH
6
7
8
9
10
11
12
13
14
APRIL 1947
GRAND RIVER BASIN, MICHIGAN
GRAND RIVER AT LANSING
APRIL 1947 FLOOD
U.S. ARMY ENGINEER DISTRICT, DETROIT

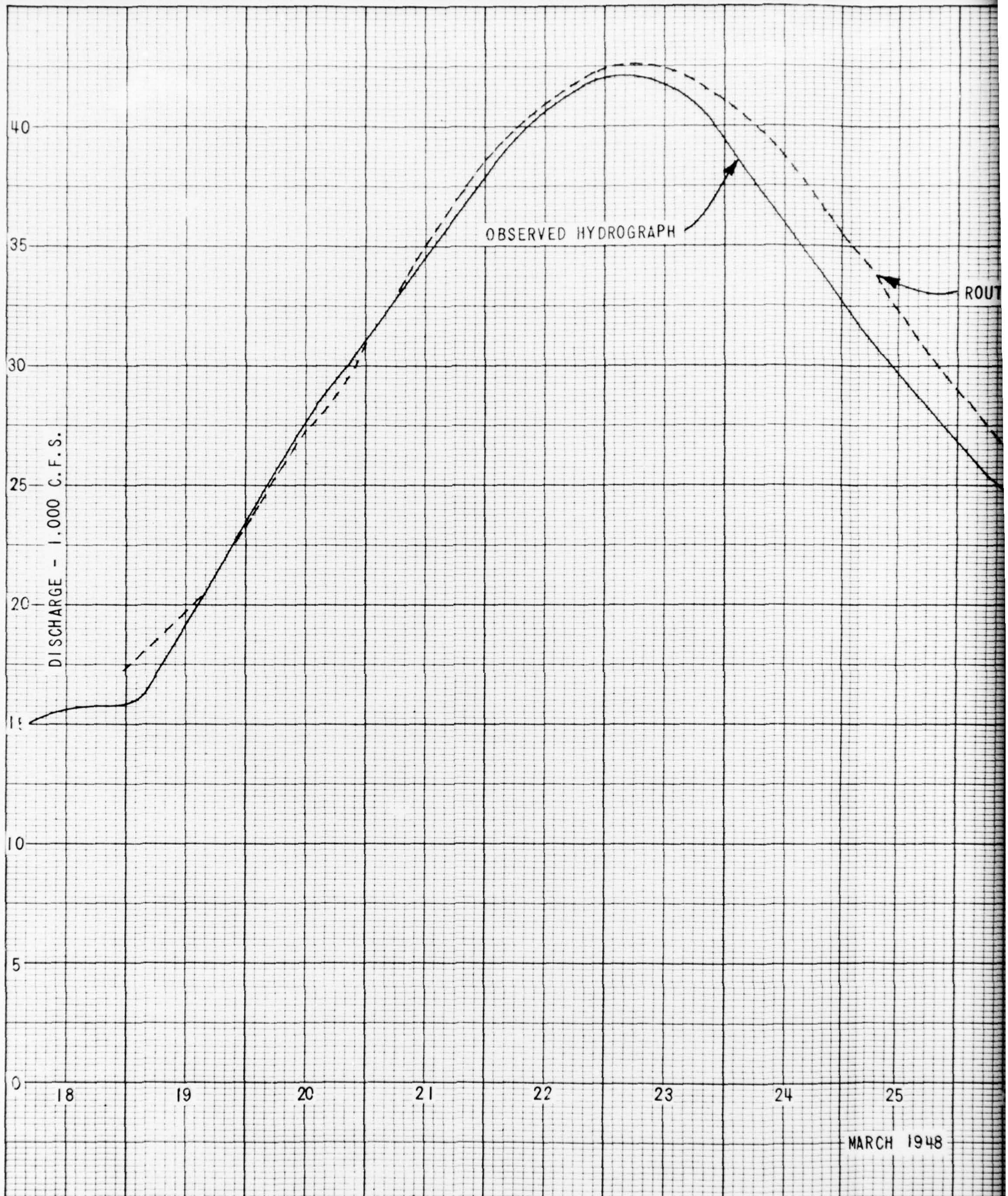


DISCHARGE - 1,000 C.F.S.
40
35
30
25
20
15
10
5
0
5
6
7
8
9
10
11
APRIL 1947
ROUTE
OBSERVED HYDROGRAPH

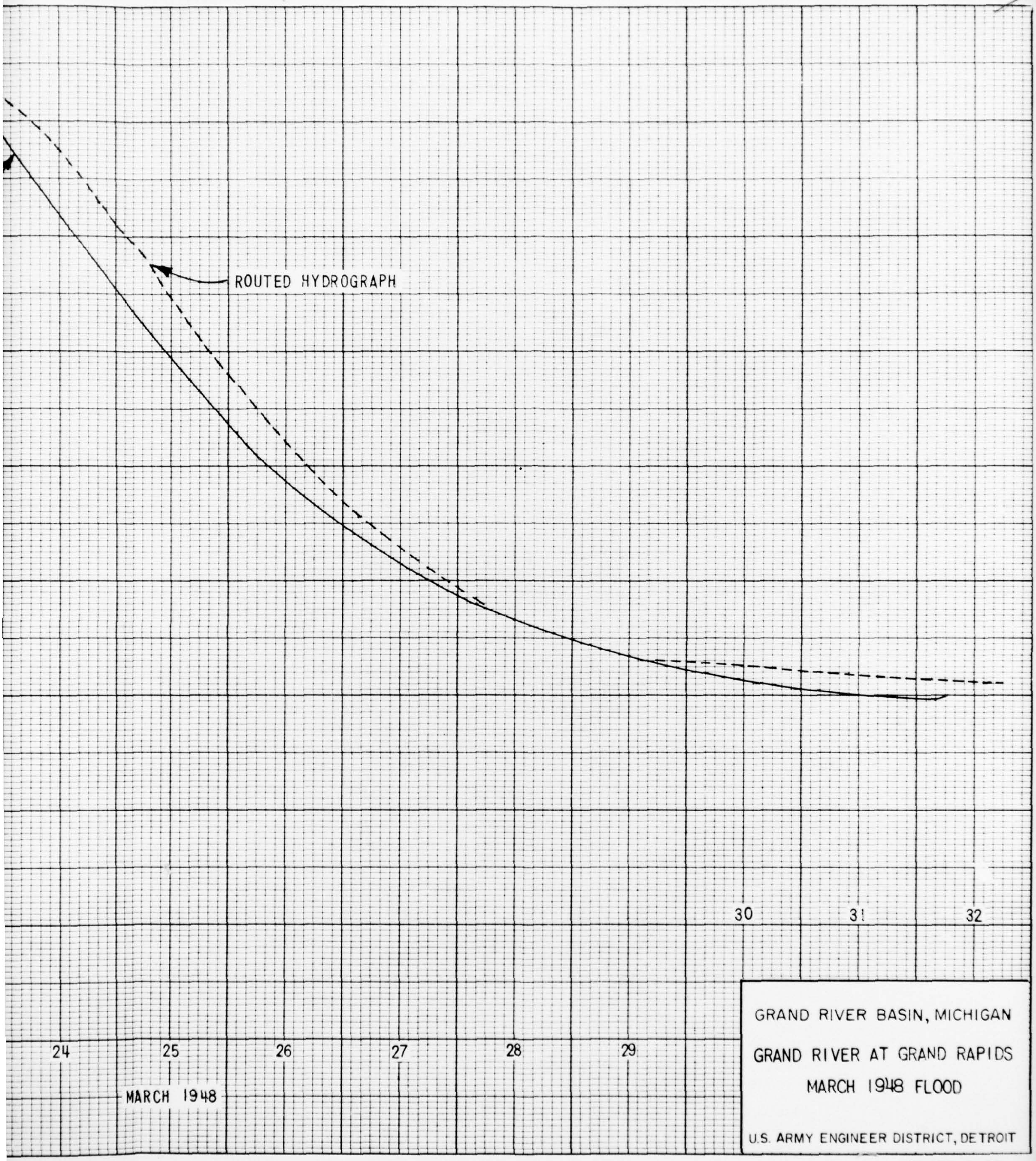


ROUTED HYDROGRAPH
ROGRAPH
GRAND RIVER BASIN, MICHIGAN
GRAND RIVER AT GRAND RAPIDS
APRIL 1947 FLOOD
U.S. ARMY ENGINEER, DISTRICT, DETROIT
10
11
12
13
14
15
16
17
18
APRIL 1947

PLATE D-21



DISCHARGE - 1.000 C.F.S.
40
35
30
25
20
15
10
5
0
18
19
20
21
22
23
24
25
MARCH 1948
OBSERVED HYDROGRAPH
ROUT

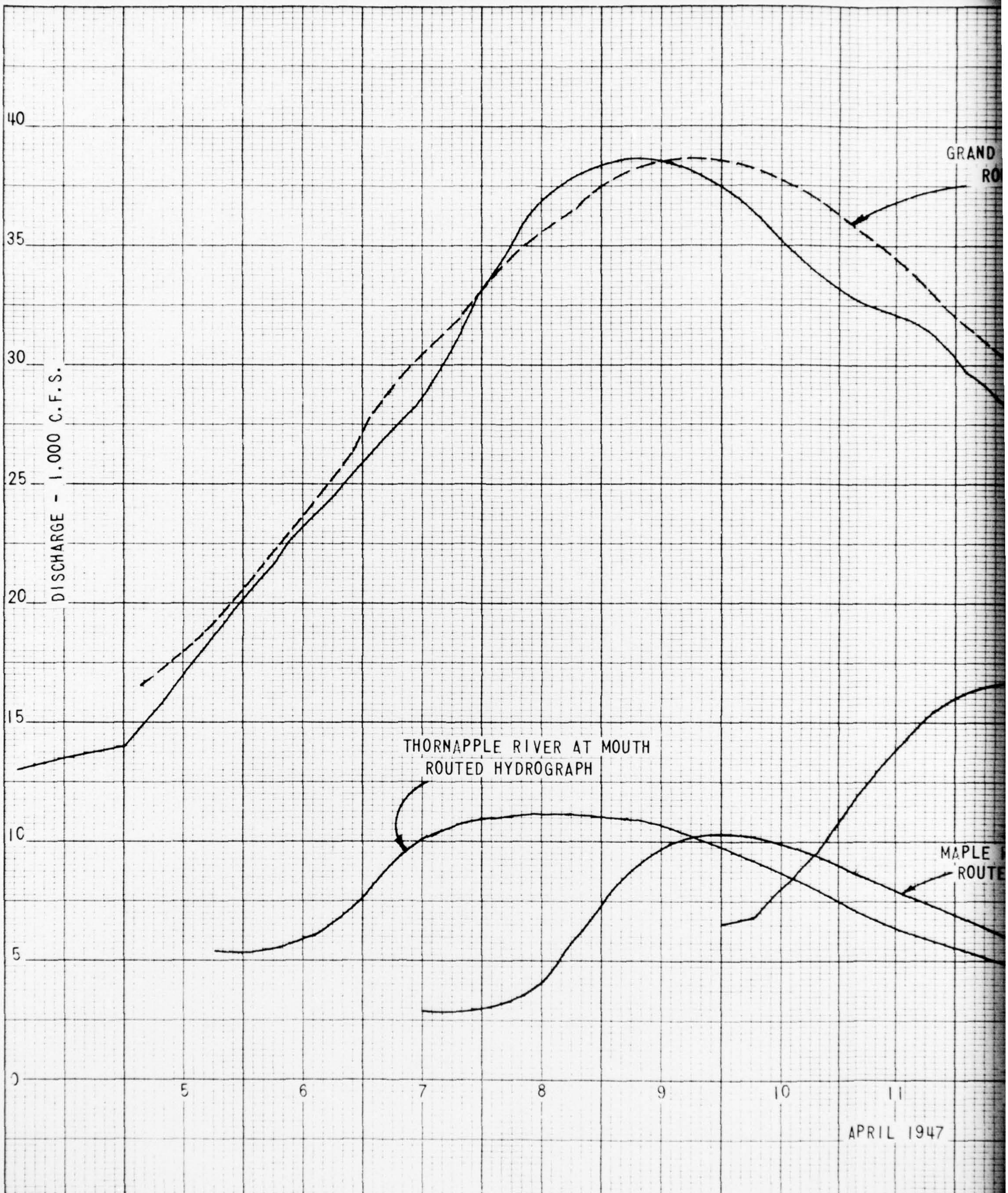


GRAND RIVER BASIN, MICHIGAN

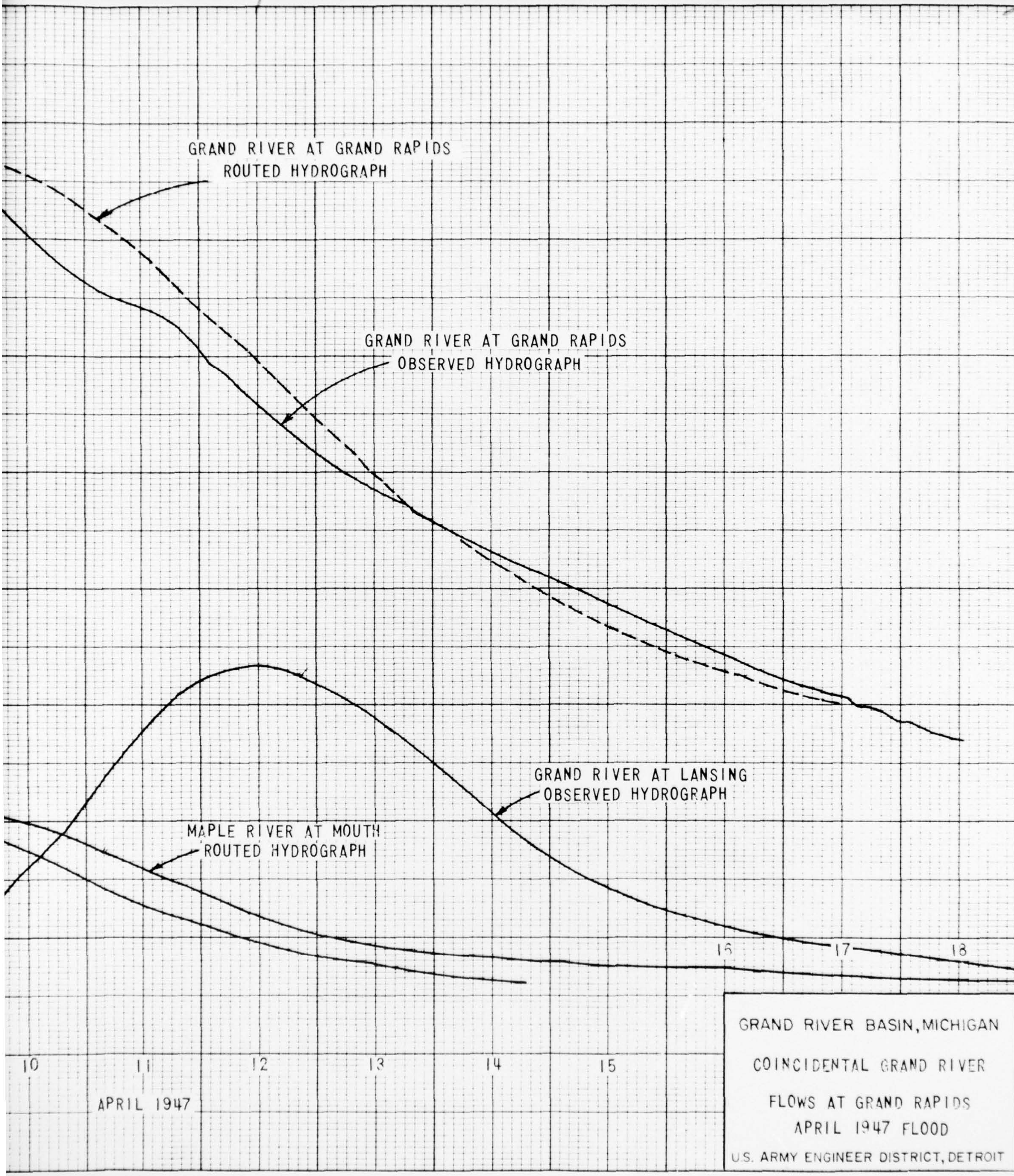
GRAND RIVER AT GRAND RAPIDS
MARCH 1948 FLOOD

U.S. ARMY ENGINEER DISTRICT, DETROIT

PLATE D-22



GRAND
RO
THORNAPPLE RIVER AT MOUTH
ROUTED HYDROGRAPH
MAPLE
ROUTE
DISCHARGE - 1,000 C.F.S.
40
35
30
25
20
15
10
5
0
5
6
7
8
9
10
11
APRIL 1947



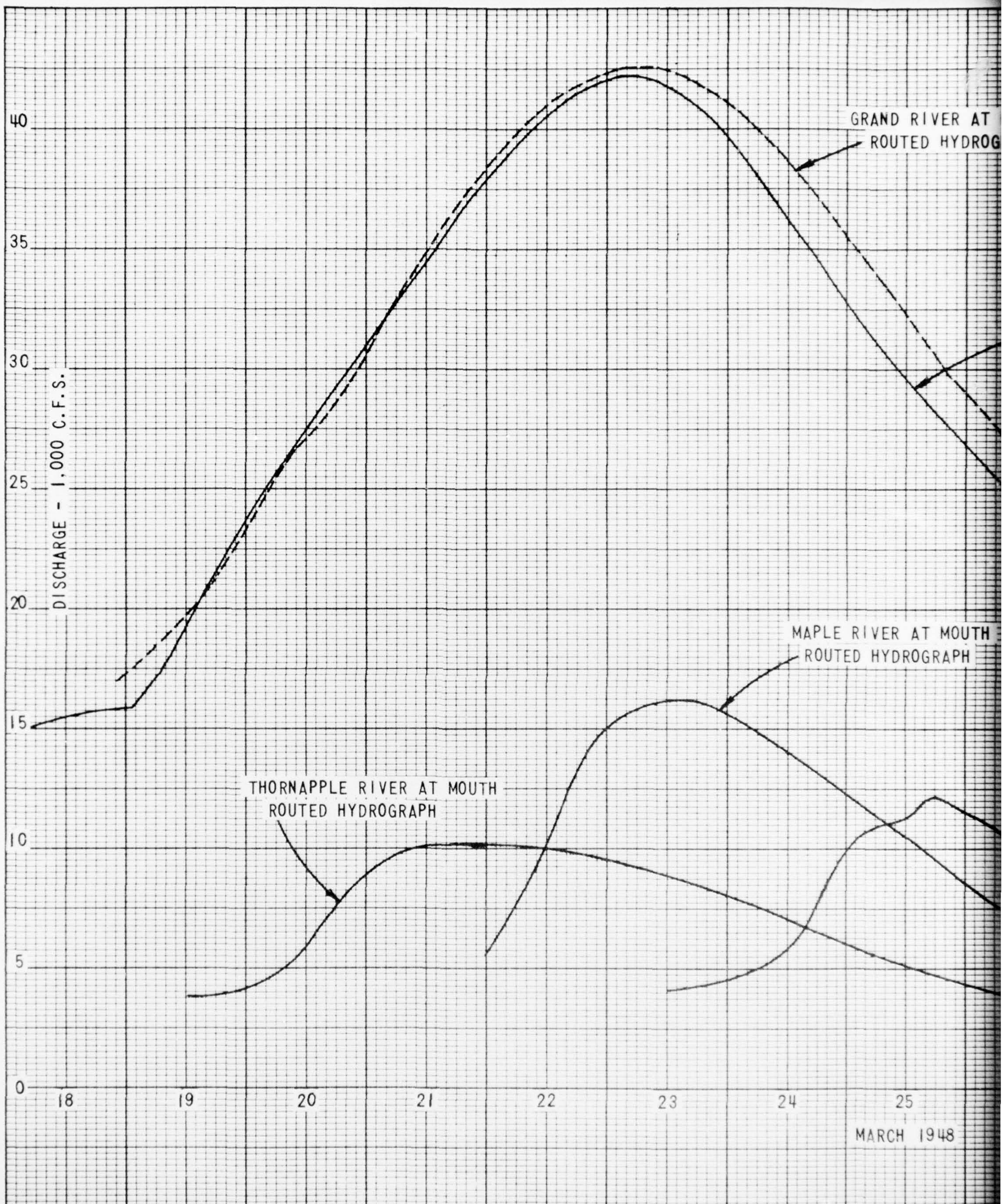
GRAND RIVER BASIN, MICHIGAN

COINCIDENTAL GRAND RIVER

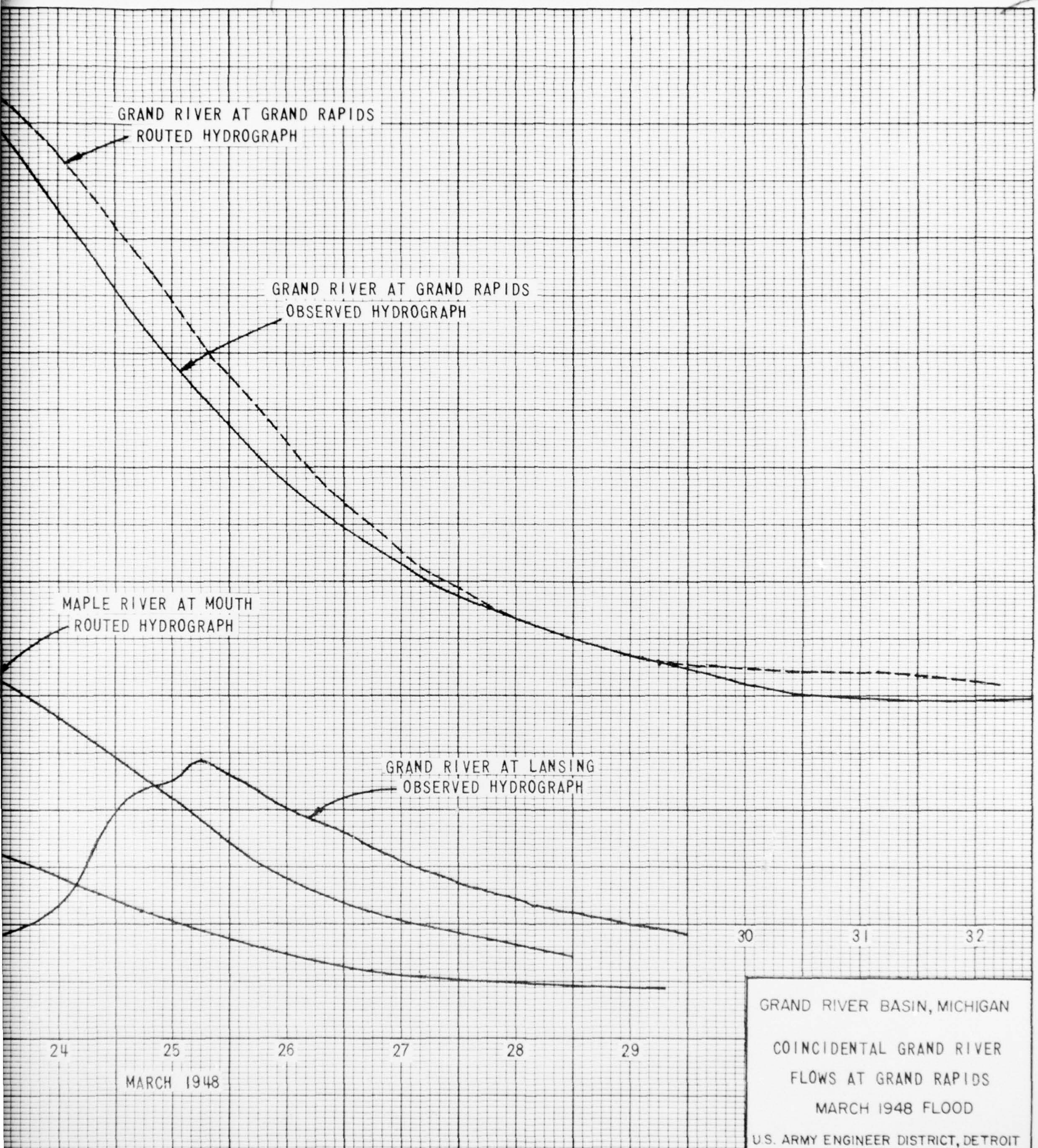
FLOWS AT GRAND RAPIDS
APRIL 1947 FLOOD

U.S. ARMY ENGINEER DISTRICT, DETROIT

PLATE D-23



GRAND RIVER AT
ROUTED HYDROG
MAPLE RIVER AT MOUTH
ROUTED HYDROGRAPH
THORNAPPLE RIVER AT MOUTH
ROUTED HYDROGRAPH
DISCHARGE - 1,000 C.F.S.
0
5
10
15
20
25
30
35
40
18
19
20
21
22
23
24
25
MARCH 1948



GRAND RIVER BASIN, MICHIGAN

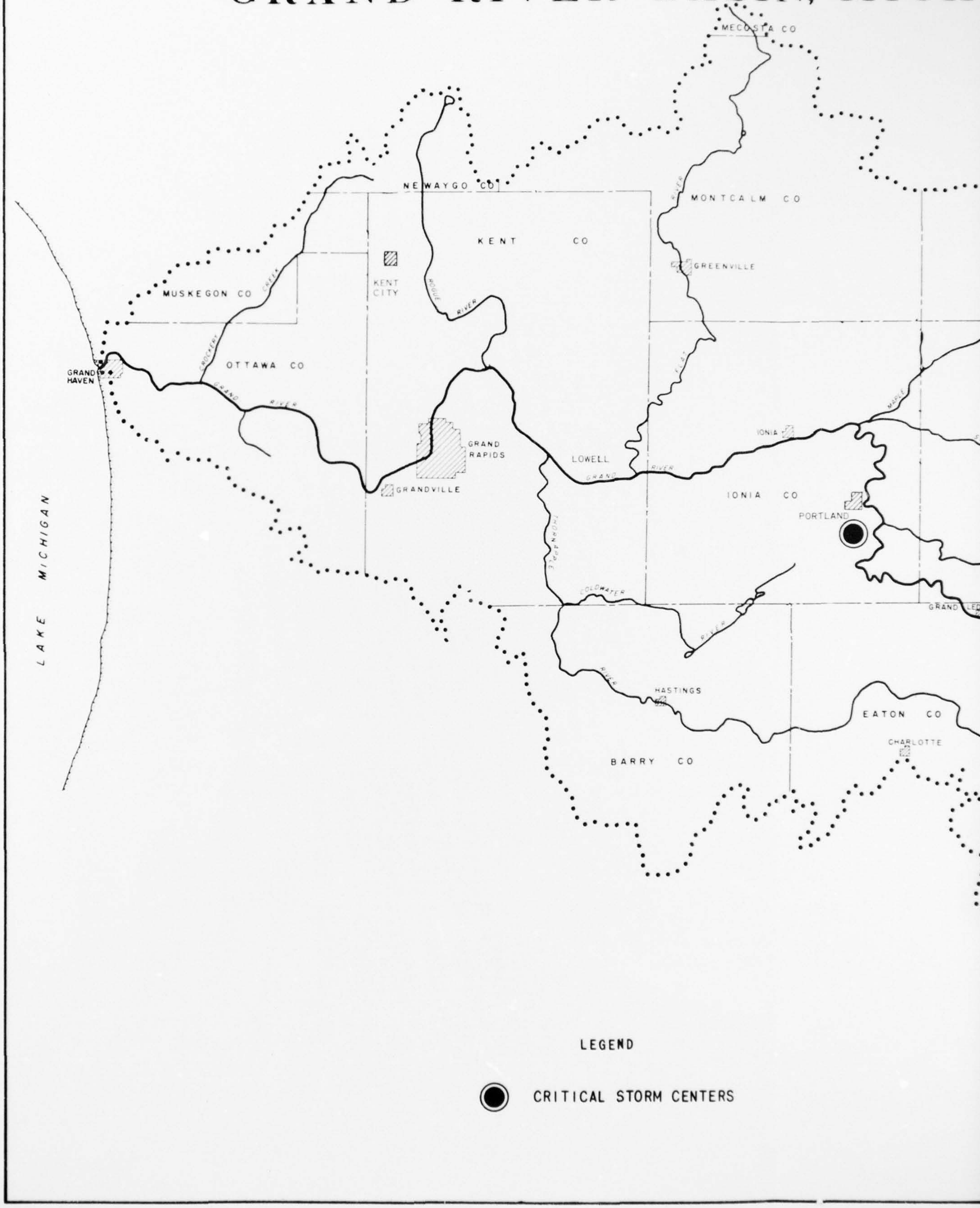
COINCIDENTAL GRAND RIVER FLOWS AT GRAND RAPIDS MARCH 1948 FLOOD

U.S. ARMY ENGINEER DISTRICT, DETROIT

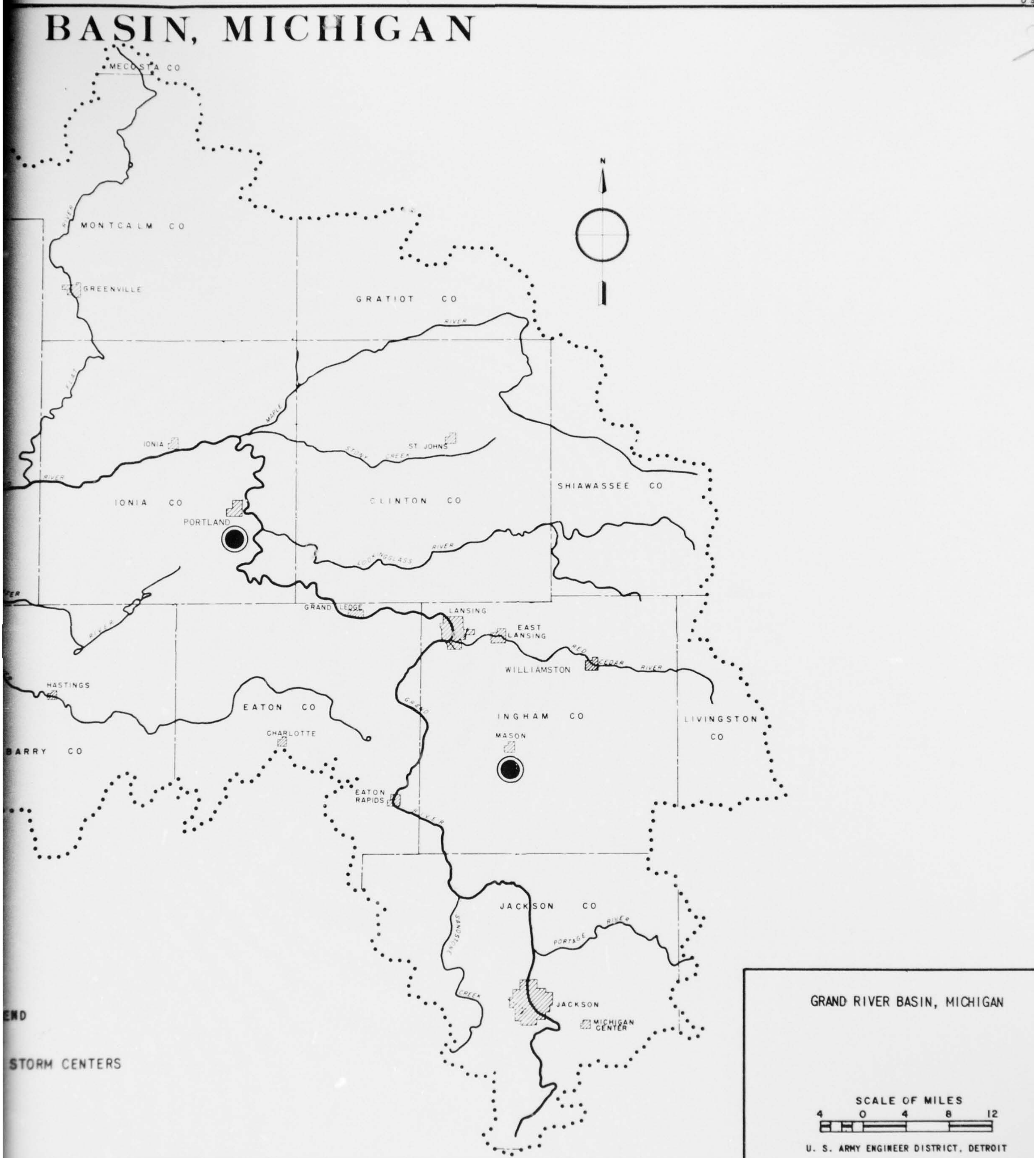
PLATE D-24

CORPS OF ENGINEERS

GRAND RIVER BASIN, MICH

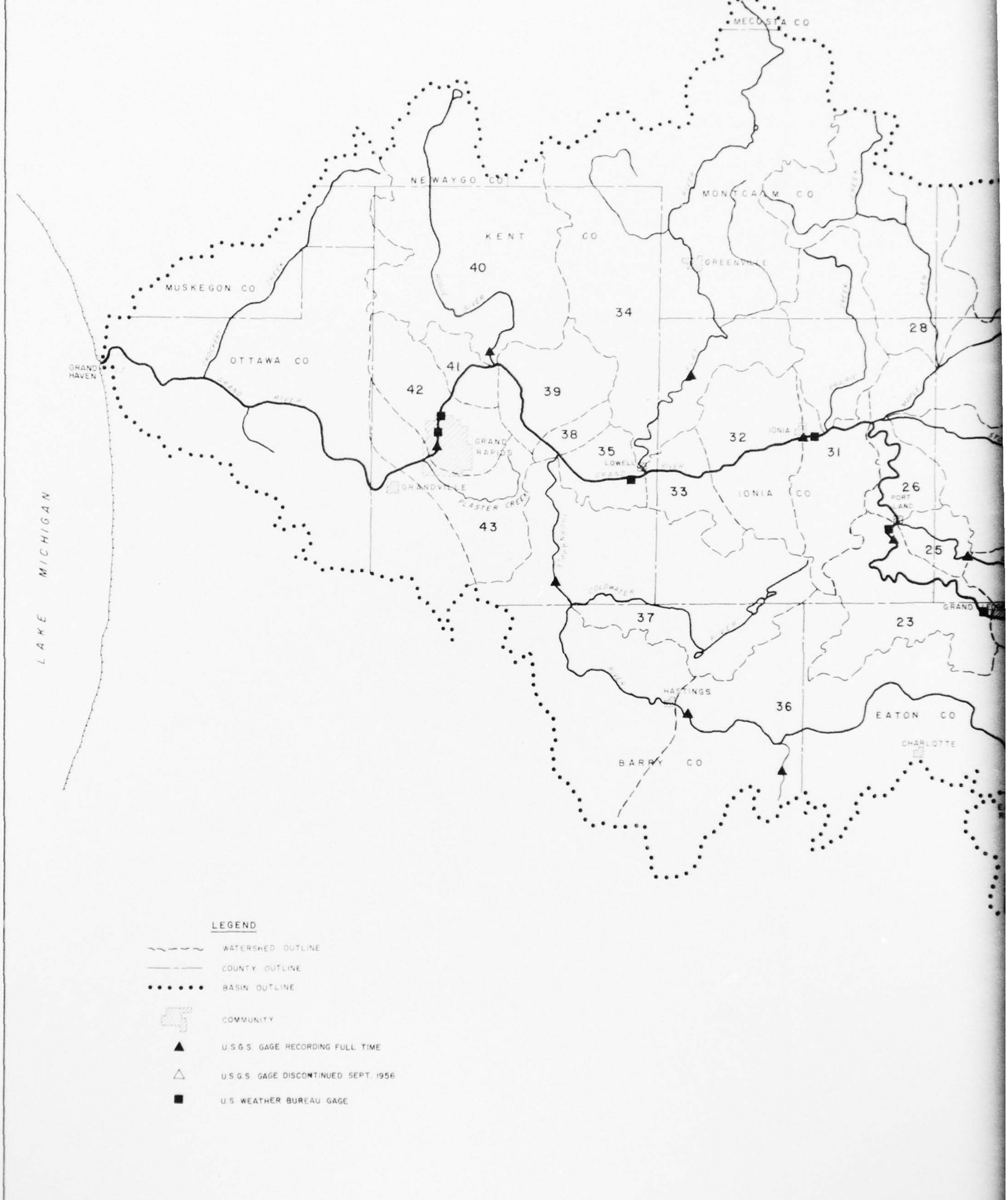


BASIN, MICHIGAN



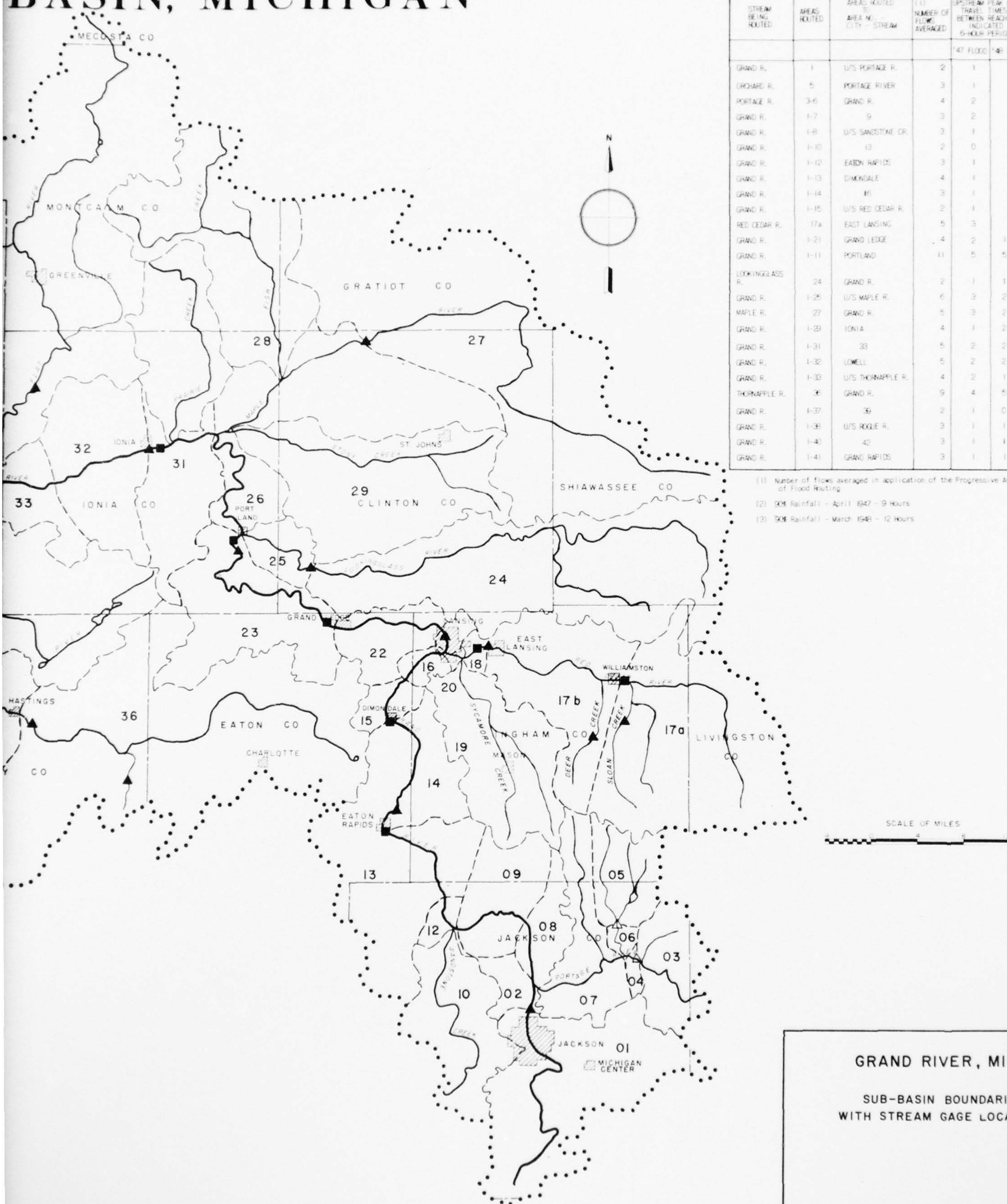
PLATE

GRAND RIVER BASIN, MICH



BASIN, MICHIGAN

U S ARMY



GRAND RIVER ROUTING STUDIES							
STREAM BEING ROUTED	AREAS ROUTED	AREAS ROUTED TO AREA NO. - CITY - STREAM	(1) NUMBER OF FLOWS AVERAGED	UPSTREAM PEAK CREST TRAVEL TIMES BETWEEN REACHES INDICATED 6-HOUR PERIODS		6-HOUR PERIOD OF PEAK OCCURENCE FROM MIDDLE OF STORM IN	
				'47 FLOOD	'48 FLOOD	(2) '47 FLOOD	(3) '48 FLOOD
GRAND R.	1	U/S PORTAGE R.	2	1		4	
ORCHARD R.	5	PORTAGE RIVER	3	1			
PORTAGE R.	3-6	GRAND R.	4	2		6	
GRAND R.	1-7	9	3	2			
GRAND R.	1-8	U/S SANDSTONE CR.	3	1			
GRAND R.	1-10	13	2	0			
GRAND R.	1-12	EATON RAPIDS	3	1		7	
GRAND R.	1-13	DIMONDALE	4	1		8	
GRAND R.	1-14	16	3	1			
GRAND R.	1-15	U/S RED CEDAR R.	2	1		10	7
RED CEDAR R.	17a	EAST LANSING	5	3		8	5
GRAND R.	1-21	GRAND LEDGE	4	2	1	11	8
GRAND R.	1-11	PORTLAND	11	5	5	16	13
LOOKINGGLASS R.	24	GRAND R.	2	1	1	6	4
GRAND R.	1-25	U/S MAPLE R.	6	3	2	18	15
MAPLE R.	27	GRAND R.	5	3	2	10	7
GRAND R.	1-29	IONIA	4	1	2	16	8
GRAND R.	1-31	33	5	2	2		
GRAND R.	1-32	LOWELL	5	2	2	18	12
GRAND R.	1-33	U/S THORNAPPLE R.	4	2	1		
THORNAPPLE R.	36	GRAND R.	9	4	5	13	8
GRAND R.	1-37	39	2	1	0		
GRAND R.	1-38	U/S ROGUE R.	3	1	1	19	14
GRAND R.	1-40	42	3	1	1		
GRAND R.	1-41	GRAND RAPIDS	3	1	1	20	16

(1) Number of flows averaged in application of the Progressive Average Lag Method of Flood Routing

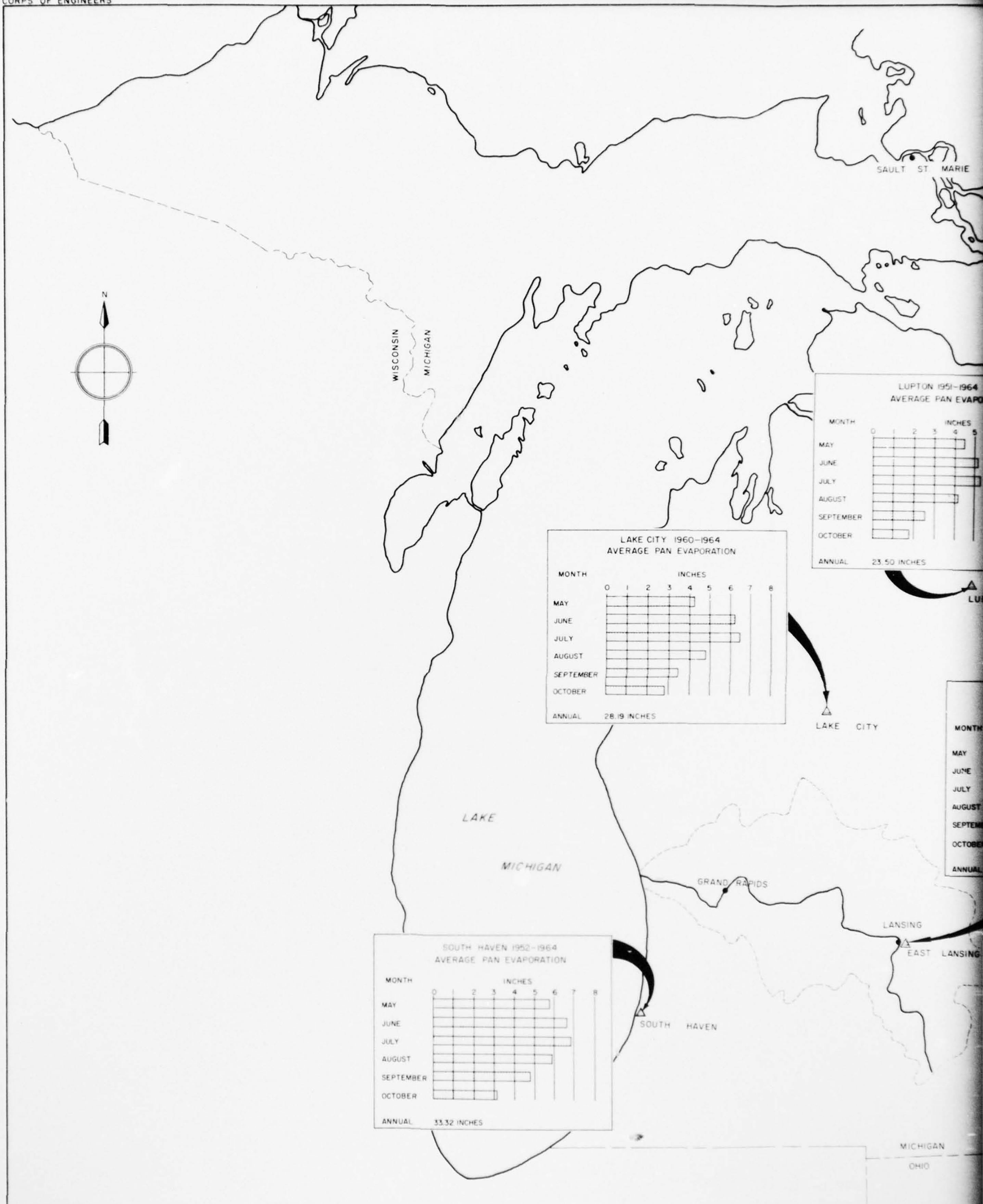
(2) 90% Rainfall - April 1947 - 9 Hours

(3) 90% Rainfall - March 1948 - 12 Hours

GRAND RIVER, MICH.

SUB-BASIN BOUNDARIES WITH STREAM GAGE LOCATIONS

31 MAY 1966


N
WISCONSIN
MICHIGAN
SAULT ST. MARIE
LUPTON 1951-1964
AVERAGE PAN EVAPO
MONTH
INCHES
0 1 2 3 4 5
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
ANNUAL 23.50 INCHES
LAKE CITY 1960-1964
AVERAGE PAN EVAPORATION
MONTH
INCHES
0 1 2 3 4 5 6 7 8
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
ANNUAL 28.19 INCHES
LAKE CITY
MONTH
MAY
JUNE
JULY
AUGUST
LAKE
MICHIGAN
GRAND RAPIDS
LANSING
EAST LANSING
SOUTH HAVEN 1952-1964
AVERAGE PAN EVAPORATION
MONTH
INCHES
0 1 2 3 4 5 6 7 8
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
ANNUAL 33.32 INCHES
SOUTH HAVEN
MICHIGAN
OHIO

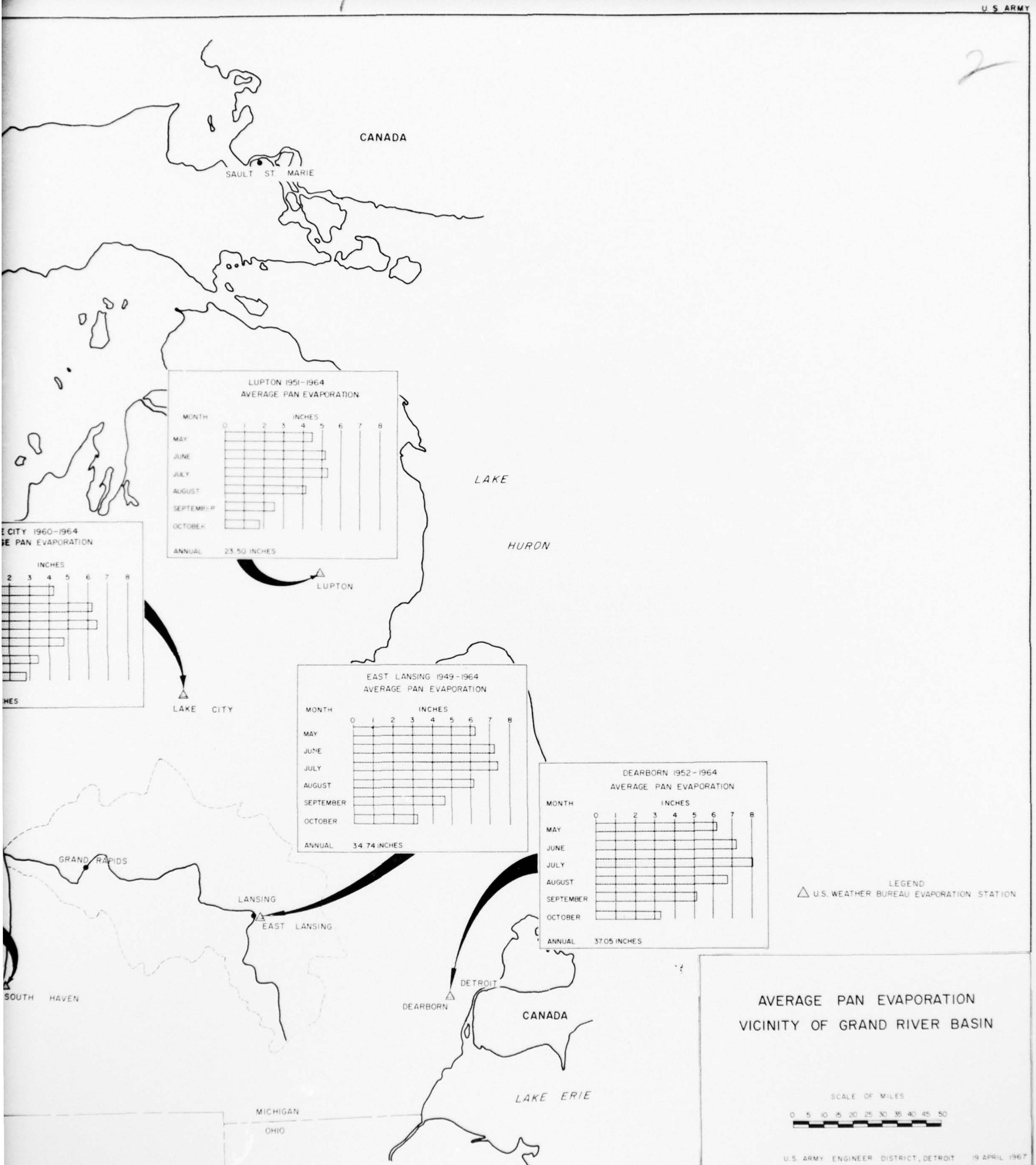
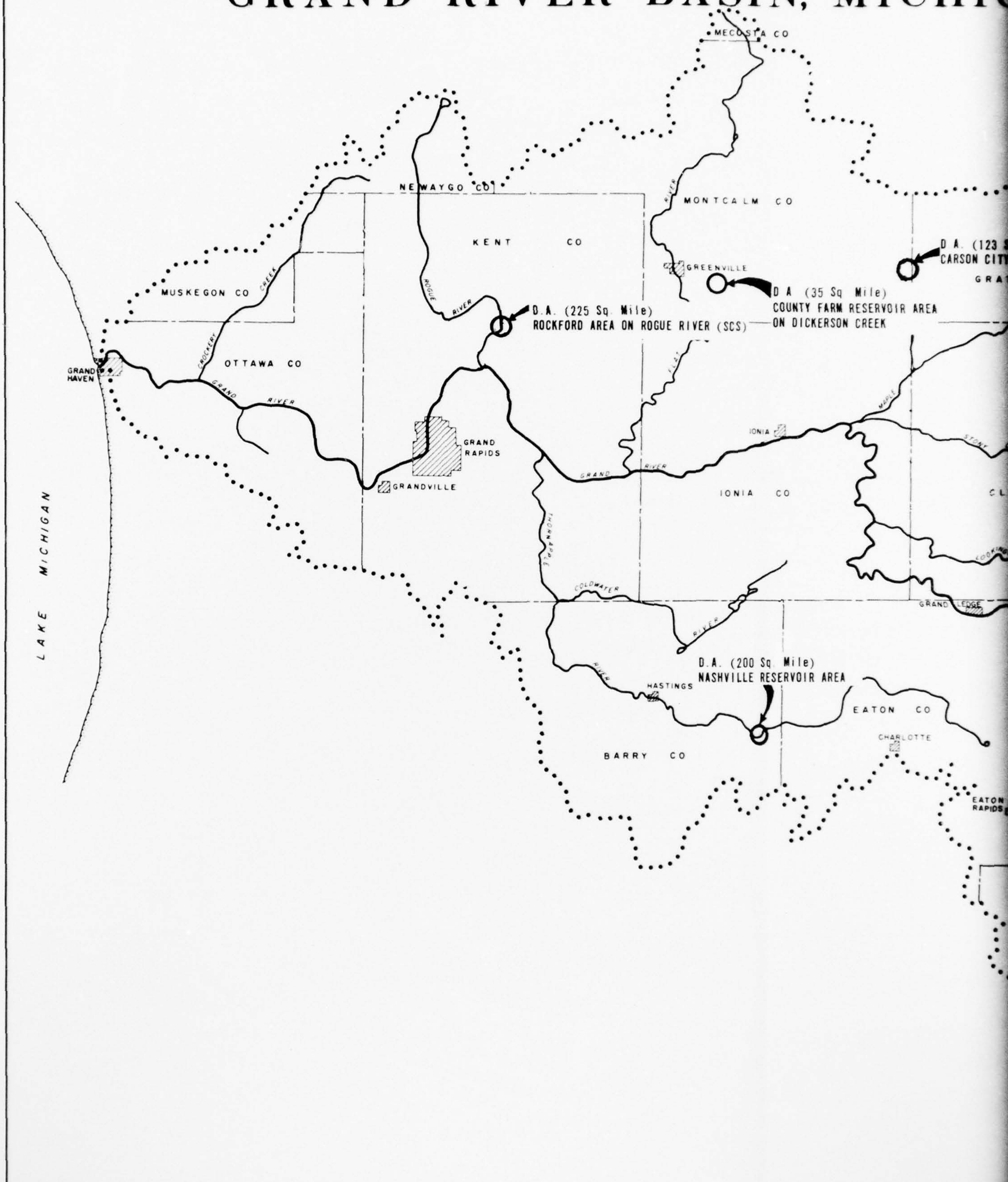

U S ARMY
CANADA
SAULT ST. MARIE
LAKE
HURON
LUPTON 1951-1964
AVERAGE PAN EVAPORATION
MONTH
INCHES
0 1 2 3 4 5 6 7 8
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
ANNUAL 23.50 INCHES
LUPTON
E CITY 1960-1964
GE PAN EVAPORATION
INCHES
2 3 4 5 6 7 8
HES
LAKE CITY
EAST LANSING 1949-1964
AVERAGE PAN EVAPORATION
MONTH
INCHES
0 1 2 3 4 5 6 7 8
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
ANNUAL 34.74 INCHES
DEARBORN 1952-1964
AVERAGE PAN EVAPORATION
MONTH
INCHES
0 1 2 3 4 5 6 7 8
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
ANNUAL 37.05 INCHES
LEGEND
U.S. WEATHER BUREAU EVAPORATION STATION
GRAND RAPIDS
LANSING
EAST LANSING
SOUTH HAVEN
DETROIT
DEARBORN
CANADA
LAKE ERIE
MICHIGAN
OHIO
AVERAGE PAN EVAPORATION
VICINITY OF GRAND RIVER BASIN
SCALE OF MILES
0 5 10 15 20 25 30 35 40 45 50
U.S. ARMY ENGINEER DISTRICT, DETROIT 19 APRIL 1967

PLATE D-27

CORPS OF ENGINEERS

GRAND RIVER BASIN, MICHI



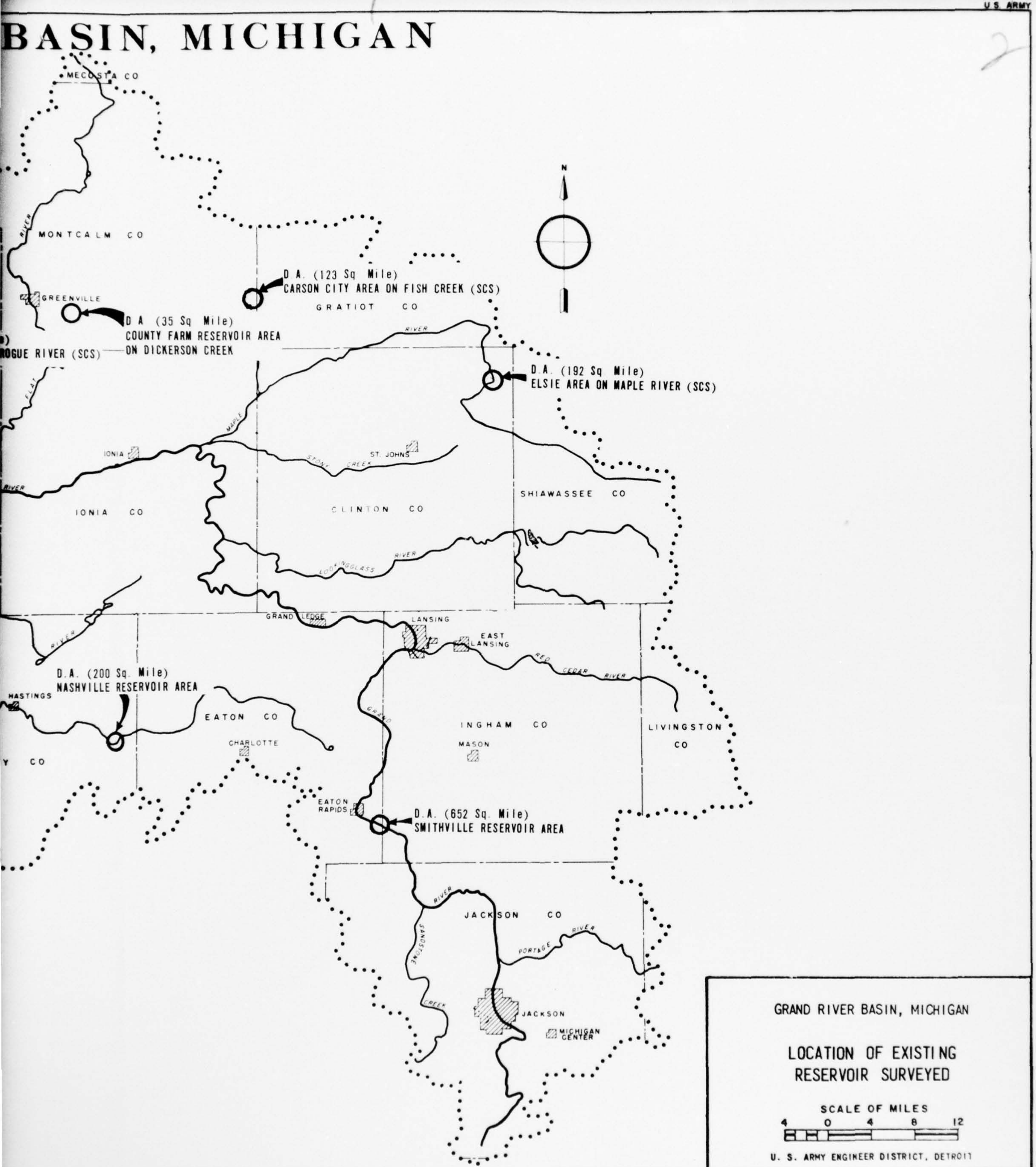

BASIN, MICHIGAN
U.S. ARMY
MECOSTA CO
MONTCALM CO
GREENVILLE
D.A. (123 Sq Mile)
CARSON CITY AREA ON FISH CREEK (SCS)
GRATIOT CO
D.A. (35 Sq Mile)
COUNTY FARM RESERVOIR AREA
ON DICKERSON CREEK
ROGUE RIVER (SCS)
D.A. (192 Sq Mile)
ELSIE AREA ON MAPLE RIVER (SCS)
IONIA
ST. JOHNS
IONIA CO
CLINTON CO
SHIAWASSEE CO
GRAND LEDGE
LANSING
EAST LANSING
D.A. (200 Sq. Mile)
NASHVILLE RESERVOIR AREA
HASTINGS
EATON CO
CHARLOTTE
INGHAM CO
MASON
LIVINGSTON CO
EATON RAPIDS
D.A. (652 Sq. Mile)
SMITHVILLE RESERVOIR AREA
JACKSON CO
JACKSON
MICHIGAN CENTER
GRAND RIVER BASIN, MICHIGAN
LOCATION OF EXISTING
RESERVOIR SURVEYED
SCALE OF MILES
4 0 4 8 12
U. S. ARMY ENGINEER DISTRICT, DETROIT

PLATE D-28